

AD/A-005 051

AUTOMATIC EXTERNAL LOAD ACQUISITION BY  
HELICOPTER

David T. Liu

System Innovation and Development Company

Prepared for:

Army Air Mobility Research and Development  
Laboratory

November 1974

DISTRIBUTED BY:

**NTIS**

National Technical Information Service  
U. S. DEPARTMENT OF COMMERCE

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER USAAMRDL-TR-74-86	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER AD/A 225751
4. TITLE (and Subtitle) AUTOMATIC EXTERNAL LOAD ACQUISITION BY HELICOPTER		5. TYPE OF REPORT & PERIOD COVERED Final Report
7. AUTHOR(s) David T. Liu		6. PERFORMING ORG. REPORT NUMBER System Technology Report 1
9. PERFORMING ORGANIZATION NAME AND ADDRESS System Innovation & Development Corp. 707 Silver Spur Rd., Suite 202 Rolling Hills Estates, Calif. 90274		8. CONTRACT OR GRANT NUMBER(s) DAAJ02-72-C-0067
11. CONTROLLING OFFICE NAME AND ADDRESS Eustis Directorate, U. S. Army Air Mobility Research and Development Laboratory Fort Eustis, Va. 23604		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS Project 1F162203AA33
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		12. REPORT DATE November 1974
		13. NUMBER OF PAGES 197
		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION DOWNGRADING SCHEDULE
16. DISTRIBUTION STATEMENT (of this Report) Approved for public release; distribution unlimited.		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		
18. SUPPLEMENTARY NOTES  PRICES SUBJECT TO CHANGE		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) Helicopter External Load Handling Automatic Load Acquisition Helicopter Automatic Cargo Handling HALAS		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number)  The objectives of this study program were to establish the system requirements, to develop conceptual designs, and to analyze the feasibility of various system designs for cargo helicopters to acquire external loads without the need for manual attachment of the load to the helicopters in a loading operation.  Current technology for handling external helicopter loads were reviewed. Applicable cargo handling technology in commercial and maritime operation was		

DD FORM 1473

Reproduced by

NATIONAL TECHNICAL  
INFORMATION SERVICEU.S. Department of Commerce  
Washington, D.C. 20540

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE(When Data Entered)

20. continued

also surveyed. The characteristics of helicopter external loads and lifting provisions were analyzed. Army air transportability requirements were established for helicopters to identify technical and operational system design requirements for automatic load acquisition. Various conceptual system designs were formulated and system feasibility analyses were conducted. Methodology was developed for conducting system trade-off studies of various design concepts. Promising system concepts were selected for further study.

The results of the study indicate that it is definitely feasible to design an automatic load acquisition system for helicopters. Although there exists a large variety of load types, a majority of principal Army helicopter loads could be handled by one automatic load acquisition system design approach. A system design that could handle the unprepared loads, loads that do not require preparation prior to hookup, will require complex load acquisition mechanization. Most of the typical Army external loads could be easily prepared for automatic load acquisition by attaching a simple lifting provision to the loads. Further design study and testing are needed to achieve practical operational system design.

1 a UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE(When Data Entered)

## TABLE OF CONTENTS

	<u>Page</u>
LIST OF ILLUSTRATIONS .....	2
LIST OF TABLES .....	5
INTRODUCTION .....	6
DISCUSSION	
1.0 Technical Approach .....	7
2.0 Review of Applicable Cargo Handling Technology .....	8
3.0 Categorization of Helicopter Loads and Analysis of Lifting Provisions .....	22
4.0 Establishment of Army Air Transportability Requirements .....	26
5.0 Presentation of Conceptual Systems .....	41
6.0 Development of System Trade-Off Methodology ..	116
7.0 System Trade-Off Analysis .....	121
8.0 Conceptual System Design ... ..	129
CONCLUSIONS AND RECOMMENDATIONS .....	157
APPENDIXES	
A. Analysis of Characteristics of External Load Types and Lifting Provisions .....	158
B. Development of Methodology for Analyzing HALAS System Performance and Requirements .....	173
LIST OF SYMBOLS .....	184



## LIST OF ILLUSTRATIONS

<u>Figure</u>	<u>Page</u>
1 Automobile Cage .....	9
2 Vehicle Spider Gear .....	10
3 Typical Tank-Hoisting Slings .....	14
4 Schematic of ALVIN, Showing the Manipulator ...	16
5 BEAVER Remotely Controlled Work System .....	18
6 Load Identification by Grid Coordinates .....	33
7 Descent to Position for Load Acquisition .....	34
8 Stabilization of Load Device to the Ship's Deck	38
9 HALAS Adjustable Lifting Cage System Concept ..	43
10 HALAS Automated Spider Gear/Frame System Concept for Handling Trucks and Wheeled Vehicles .	45
11 Lifting Loop HALAS Concept .....	51
12 Lifting Loop and Hook Engagement Detail .....	52
13 Lifting Loop for Tracked Vehicles .....	54
14 Lifting Loop for Trucks .....	55
15 Lifting Loop Straps Concept .....	57
16 Acquisition of Army Aircraft and Helicopters - Lifting Frame on Straps Concept .....	58
17 Typical Implementation of the Lifting Loop HALAS Concept for Handling Tanks and Tracked Vehicles .....	59
18 Versatility of Lifting Loop HALAS Concept .....	61
19 Implementation of the Lifting Loop HALAS System Concept .....	63
20 Conceptual Design of an Erectable Cargo Lifting Loop .....	64
21 Curved Arch Lifting Loop Design .....	65

## LIST OF ILLUSTRATIONS - Continued

<u>Figure</u>		<u>Page</u>
22	Typical Design of the Spreader Beam With Hook Arms for the Lifting Loop HALAS Concept .....	67
23	Electric-Motor-Driven Worm Gear Mechanism for Tong-Hook Acquisition Device .....	69
24	One Mode of Lifting Loop Hookup by Tong-Hook Acquisition Device .....	71
25	Small Test Model of Lifting Loop Acquisition Device .....	73
26	Exploratory Test Setup of Lifting Loop Load Acquisition Concept .....	75
27	Forcep HALAS Design Concept .....	79
28	Forcep Automatic Load Acquisition System Operation .....	81
29	Lifting Stud/Fork-Claw HALAS System Conceptual Design .....	82
30	Typical Operation of the Lifting Stud/Fork-Claw HALAS System Concept .....	84
31	Lifting Stud With Self-Guiding/Homing Receptacle HALAS Conceptual Design .....	85
32	Application of the Lifting Stud With Self-Guiding/Homing Receptacle HALAS Concept .....	87
33	Typical Electromagnetic HALAS System Concept ..	89
34	Fully Automatic HALAS Design Concept for Unprepared Army Loads .....	94
35	Conceptual Design of Hook Guiding Rods With Actuators and Specially Designed Load Acquisition Hook .....	95
36	Magnetic Hook/Lifting Ring HALAS Concept .....	100
37	Feasibility Model Testing for Magnetic Hook/Lifting Ring HALAS Concept .....	103

## LIST OF ILLUSTRATIONS - Concluded

<u>Figure</u>		<u>Page</u>
38	Design of Adjustable Load Spreader Frame for Magnetic Hook/Lifting Ring HALAS Concept .....	105
39	Application of the Magnetic Hook/Lifting Ring HALAS Concept to Automatic Acquisition of Army Trucks .....	108
40	Design of Lifting Adapter to the Existing Lifting Provision Between Rear Drive Wheels for Typical Trucks .....	109
41	Alternate Design Approach of Lifting Adapter to the Existing Lifting Provision Between Rear Drive Wheels for Typical Trucks .....	111
42	Corner Protector Design for Lifting Sling Adapter on Typical Trucks .....	112
43	Magnetic Hook HALAS System Concept Feasibility Test Model .....	115
44	Lifting and Engagement Device With Magnet-Aided Hooks - Basic Layout of Components .....	134
45	Sizes of Structural Elements Frame and the Spreader Beam - Nominal .....	135
46	Structural Details of Frame Construction Lifting Lugs Adjustable Crosswise .....	136
47	Lifting Rod Assembly .....	137
48	Design Details of Engagement Assemblies: Hook and Lifting Eye .....	138
49	Design Details and Dimensions for the Main Hook	139
50	Magnetically Aided Engagement Principle of Operation .....	140
B-1	Configuration of Helicopter With Load Acquisition System .....	174
B-2	Dynamic System Model .....	175

## LIST OF TABLES

<u>Table</u>		<u>Page</u>
1	Configuration Data for Army Tanks & Tracked Vehicles .....	48
2	Longitudinal and Transverse Beam Length Requirement for the Adjustable Spreader Beam Design .....	106
A-1	Combat Equipment .....	159
A-2	Combat Service Units .....	163
A-3	Transportation Equipment .....	167
A-4	Construction Equipment .....	171

## INTRODUCTION

Equipment and procedures presently being used for acquiring helicopter external loads evolved to meet specific requirements as they arose, with little consideration given to the overall transportation system problem. The current procedure for ground hookup of external helicopter loads generally requires crewmen, who are positioned underneath the helicopter, to manually attach the load. This procedure can be extremely slow and subjects the crewmen to an uncomfortable and dangerous environment. The time involved to place the ground crew at the scene prior to hookup, and retrieval of crew after hookup, would be unacceptable during certain types of missions. Attachment of external loads to hovering helicopters will become even more critical as helicopter capacities become larger and as tension members and payloads become more awkward to handle. Proper interface design between the helicopter load acquisition system and the load with automatic load acquisition provisions would greatly enhance the helicopter efficiency and productivity.

The purpose of this study effort was to establish design requirements and to develop system designs for a helicopter automatic load acquisition system (HALAS). Current and future generation cargo helicopters having a lift capability up to 60,000 pounds were considered in this study program.

This report presents the system analyses leading to the formulation of the various HALAS concepts, the feasibility analyses, system trade-off methodology, and the conceptual design of the selected promising concepts. Conclusions from this study and recommendations for further investigation are also included.

## 1.0 TECHNICAL APPROACH

The technical approach to accomplish the study program was first to review the current technology including procedures and interface equipment for handling external helicopter loads. Commercial and maritime applicable technology in cargo handling was also investigated. Aerospace technology in linkup operation, manipulator designs, and load handling devices in undersea operation was also studied for possible application in the design of an automatic load acquisition system. The knowledge of the applicable current technology was beneficial in formulating the various conceptual HALAS designs and in determining the system feasibility. The helicopter external loads were then categorized according to their commonality in configurations, size, weight, mission application, and their lifting provision designs. The characteristics of various lifting provision designs of the helicopter external loads were then analyzed to determine the design requirements of the automatic load acquisition equipment for handling the various loads. By analyzing the characteristics of the various loads and their lifting provisions, the design requirements for the automatic load acquisition were established and the versatility of the HALAS concepts were optimized.

The Army air transportability requirements applicable to both current and future helicopters with external load handling capabilities were then established for the purpose of identifying those critical, operational, and technical areas where external load acquisition problems exist. The requirement for the automatic load acquisition system included the identification of guiding and positioning information under various visibility and operating conditions. The above approaches established the background and requirements for designing the helicopter automatic load acquisition system. Various HALAS system concepts were formulated for handling prepared and unprepared loads. Both single- and tandem-rotor helicopters were considered along with single- or multiple-lifting sling arrangements.

The methodology for conducting the system trade-off studies between various system concepts was then developed and used to evaluate the system effectiveness and to select the optimal design concept.

## 2.0 REVIEW OF APPLICABLE CARGO HANDLING TECHNOLOGY

Applicable technology in commercial and maritime cargo handling operation has been reviewed. Current helicopter external load handling techniques and applicable aerospace technology have also been surveyed. The purpose of these reviews was to determine the applicability of current load handling technology and to provide direction for achieving the objectives of this study program.

### 2.1 MARITIME CONTAINER HANDLING EQUIPMENT

Multiple variations of container spreaders for ship or shore crane operations are available. Automatic twist-locks, mechanical or electromechanical/hydraulic, are applicable to helicopter operation. Current commercial and maritime container spreaders, fixed or adjustable, are neither designed nor mechanized for airborne operation.

#### Automobile Cage

When hoisted, the telescoping frame slides up until it meets the stopper and in the meantime pulls a cable toward the hinged ramp, thus tilting it up to form a wheel stop to hold the automobile in place. When one end of the cage is lowered onto a tilting block, the frames collapse, allowing gravitational release. See Figure 1.

#### Vehicle Spider Gear

The spider gear (Figure 2) opens to allow lower hooks to be set in place under the wheel. When positioned, the hooks are pulled close together to hold the vehicle for hoisting. Because this gear requires four men to place it into position and four men to remove it, it is a slower, more costly operation than the automobile cage approach.

#### Small Craft Slings

To prevent costly boat damage, three basic hoisting methods have been devised:

1. Built-in lifting rings or padeyes can be used, when available. Generally there are three contact points (one forward, two abreast aft) to assure upright stability.
2. A load can be hoisted in its bridle with four leads connected to four points on the spreader base with a top spreader to prevent the four leads from touching the craft.

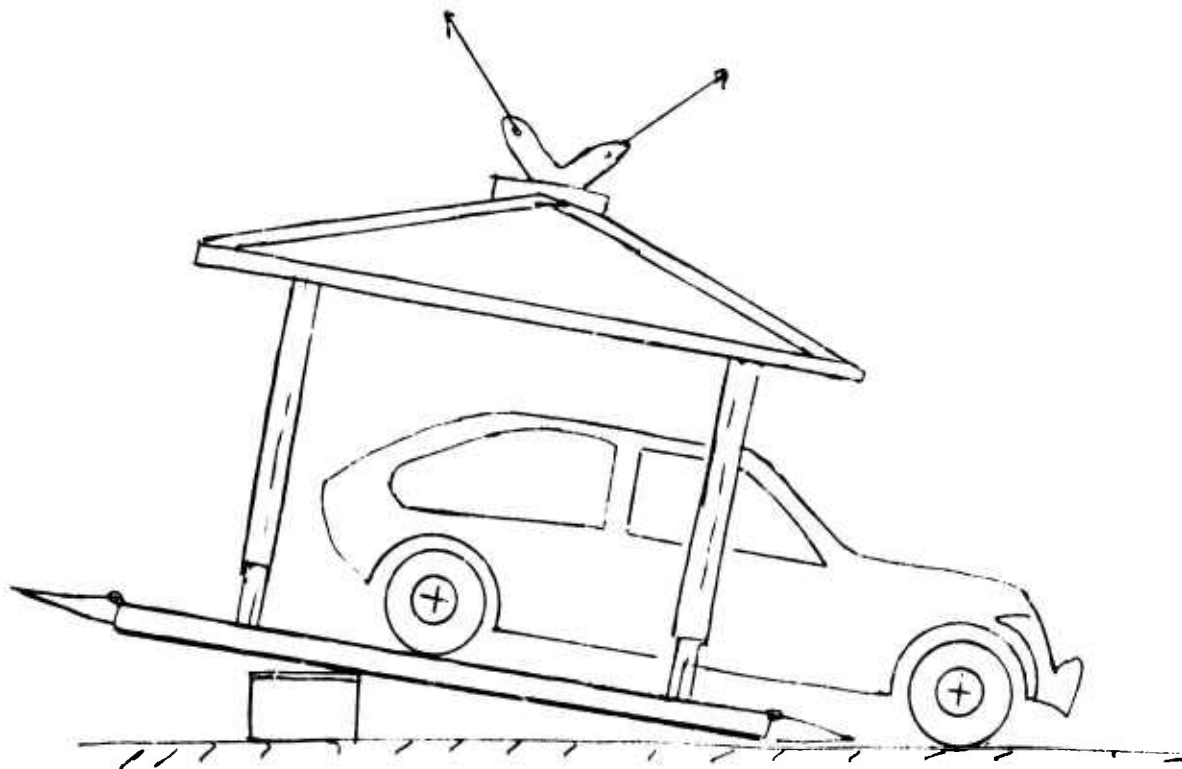
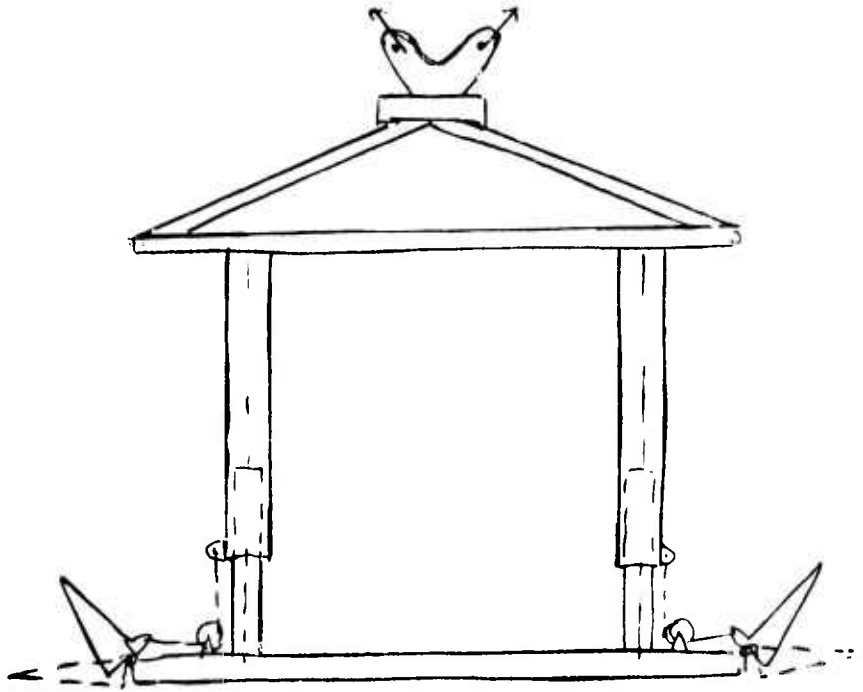


Figure 1. Automobile Cage.



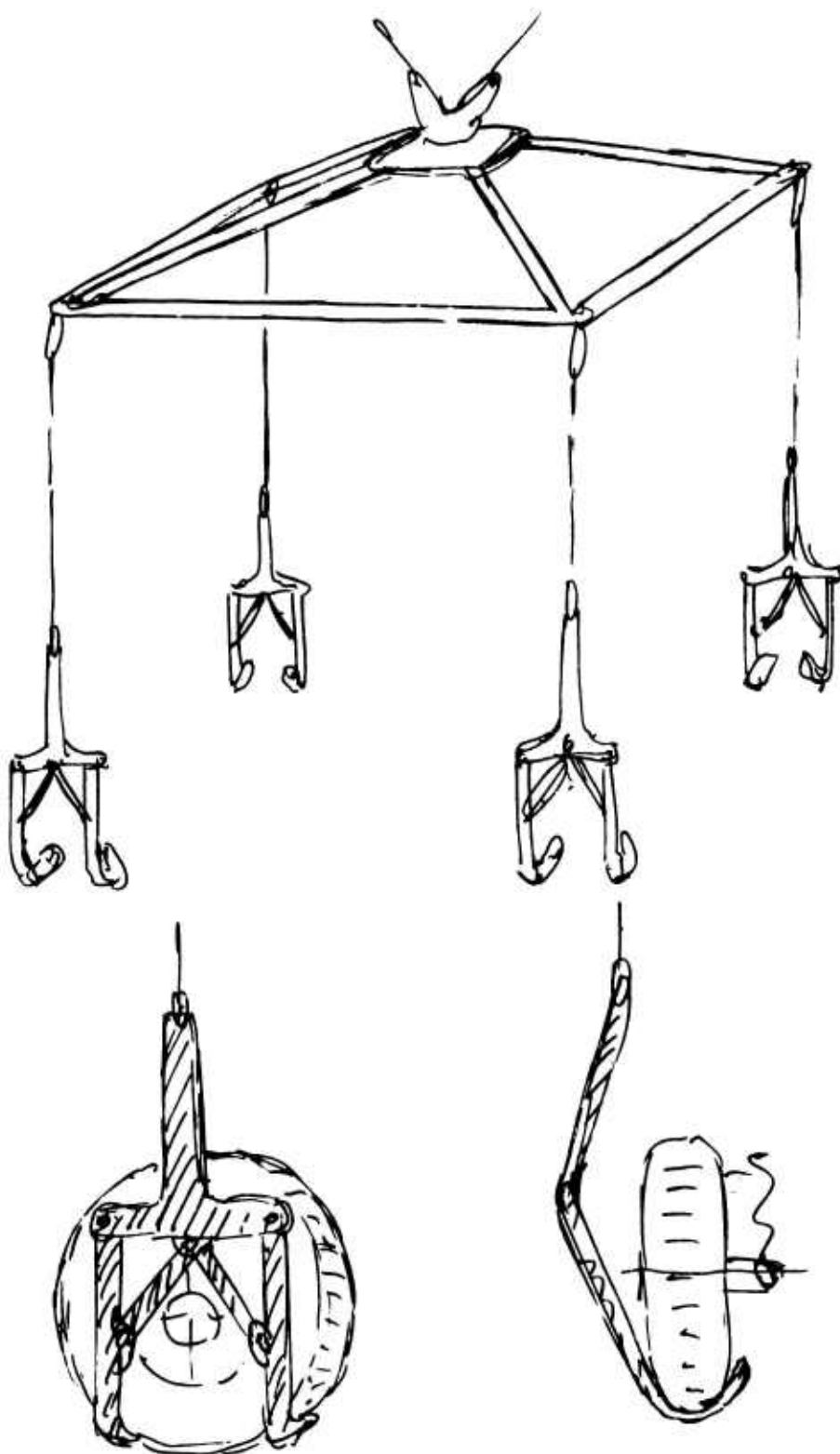


Figure 2. Vehicle Spider Gear.

3. Web steel or nylon straps, kept away from boat sides by spreaders, provide a simple, quick, efficient method of handling.

Cradles, lifted with the boat when the boat is to remain on land, are handled in a manner similar to the methods listed above.

#### Newsprint Handling

Presently, newsprint is being handled by vacuum suction devices placed onto the side of the roll; special compressor-type motors are used.

An alternate method is the use of cascade clamps attached to a forklift; the clamps grasp two sides of the load and are then squeezed together hydraulically for hoisting.

A scissor type clamp is also used when rolls are laid down on their sides. This type of clamp could adapt to drums, engine cases, etc.

#### Vacuum Equipment

As explained above in newsprint handling, vacuum clamp equipment works to considerable advantage with drums and nonporous surfaces due to ease and speed of operation as well as damage-free operation.

#### Cargo Containers

Container handling begins at the point of receipt at the steamship terminal and continues through the facility and into the stowage area aboard ship. Cargo in a sealed container arrives at the terminal on a chassis and will be handled one of two ways: It will be left on the chassis for transport to ship at the time of loading, or it can be removed from the chassis by a transtainer (container lifting and transporting equipment) and placed on the dock to await shipment. The chassis-bound container will be pulled under the container gantry and hoisted into the stowage area aboard ship. The container on the dock will be directed by the transtainer to a pickup point adjacent to the container pile, where a carry-all, forklift, or forklift with a container spreader will pick up the container and transport it to the loading position under the gantry crane. The gantry crane, using an adjustable container spreader, will pick up and hoist the container into the stowage area.

### Open-Top Containers

The two remaining types of containers are racks and gondolas. A gondola is open at the top, 8 feet wide, 4 feet high, and 20 feet long. A rack is open at the top, sides and ends, and is available in two sizes: 8 feet wide by 20 feet long, and 4 feet and 8 feet high. Open-top containers are used for high-density cargo, machinery, vehicles, pipe and steel products, or any cargo difficult to containerize. Open containers can be stacked and locked with twist-lock connectors; however, due to the capacity of 46,000 pounds each, only one rack or gondola can be lifted at a time. Utilizing the interfacing equipment designed for regular containers, racks or gondolas are suitable for automatic load acquisition.

### Unit Loads

A cargo unit load is a 1-ton lot placed on a palletboard and strapped, sometimes glued with semipermanent glue, to the pallet. Methodology for handling unit loads falls into several categories; i.e., use of a C-fork, a cage, or slings.

The advantage of the C-fork is tight stowage of the unit load, and ease of placement of the load and removal of the fork from the open side. It is used for permanent stowing only within direct reach of the ship's gear. If wing stowage is required, it must be landed in the hatch square and moved into the wings by forklifts. For wing stowage, the cage is generally used.

The cage is a platform usually capable of handling two unit loads simultaneously. The platform is generally 5 feet by 15 feet. Reduced manning and increased production are cage advantages. On the dock apron, two unit loads are placed on the cage platform by front-men; the cage is then hoisted into the vessel, where loads are removed by forklift and placed in final stowage location.

For small necessary key storage areas, inaccessible to C-fork or cage loading, cargo slings are used on unit loads. Leaving the slings on the loads expedites immediate discharge.

### Containerized Unit Loads

Container methodology is being improved. Adaptation of unit load size for rapid loading and unloading with small forklifts can be accomplished by reducing the size of the unit load to no more than 3 feet 6 inches wide and 3 feet 6 inches high, permitting units to be stowed two-wide and two-high for the length of the container.

## Bridles and Slings

Bridles and slings of various types have been the traditional cargo handlers for ships.

A bridle is a sling with a rigid bar to prevent the sling from crushing the load or pallet edges. Bridles consist of two slings with a bar and require a 5- to 6-inch lip overhang on each end of the pallet. The pallet is picked up by sliding the bar into the recessed lip area for hoisting. Of the many variations of bridles or spreaders designed to lift cargo without crushing or damaging, a prime example is the type used for automobiles or vehicles which prevents the hoisting cables from coming in contact with vehicle sides or ends.

Cargo slings (Figure 3) come in every size, length and capacity possible, with no limitations on specific uses. The advent of the forklift, squeeze-lift, or unit loads reduced and relegated the use of slings to handling heavy equipment, steel products, or units too large and heavy to be handled by pallets, bridles and C-forks.

## Block Stowage

The development of larger oceangoing vessels and cargo handling equipment necessitates stowing all types of cargo, allowing 5- to 15-ton drafts per hoist. To accomplish this requires both vertical and horizontal dunnage placed, at the time of stowage, around each draft (or hoist); otherwise, the discharging port would have to move the cargo out of solid stowage into a position where slings could be placed around the load preparatory to hoisting. With block stowage, the discharging port merely slides the sling around the load (separated by dunnage) and hoists it to the pier. Where cargoes are preslung, one or more hooks in the eyes of splices accomplish the hoist. Such operational expediency should be considered when configuring the automatic load acquisition system in ship loading and unloading operations.

## 2.2 ADVANCED LOAD ENGAGEMENT SYSTEM TECHNOLOGY

The present approach to load acquisition and engagement requires one (or more) crewman on the ground or on the load to engage the lifting lines with the attachment points, which either are a part of the load or are the result of prior "load preparation" for lifting. Each type of load may have different engagement features. Industry-wide standardization of load lifting features would facilitate and improve lifting efficiency and enhance the automatic load acquisition operation.

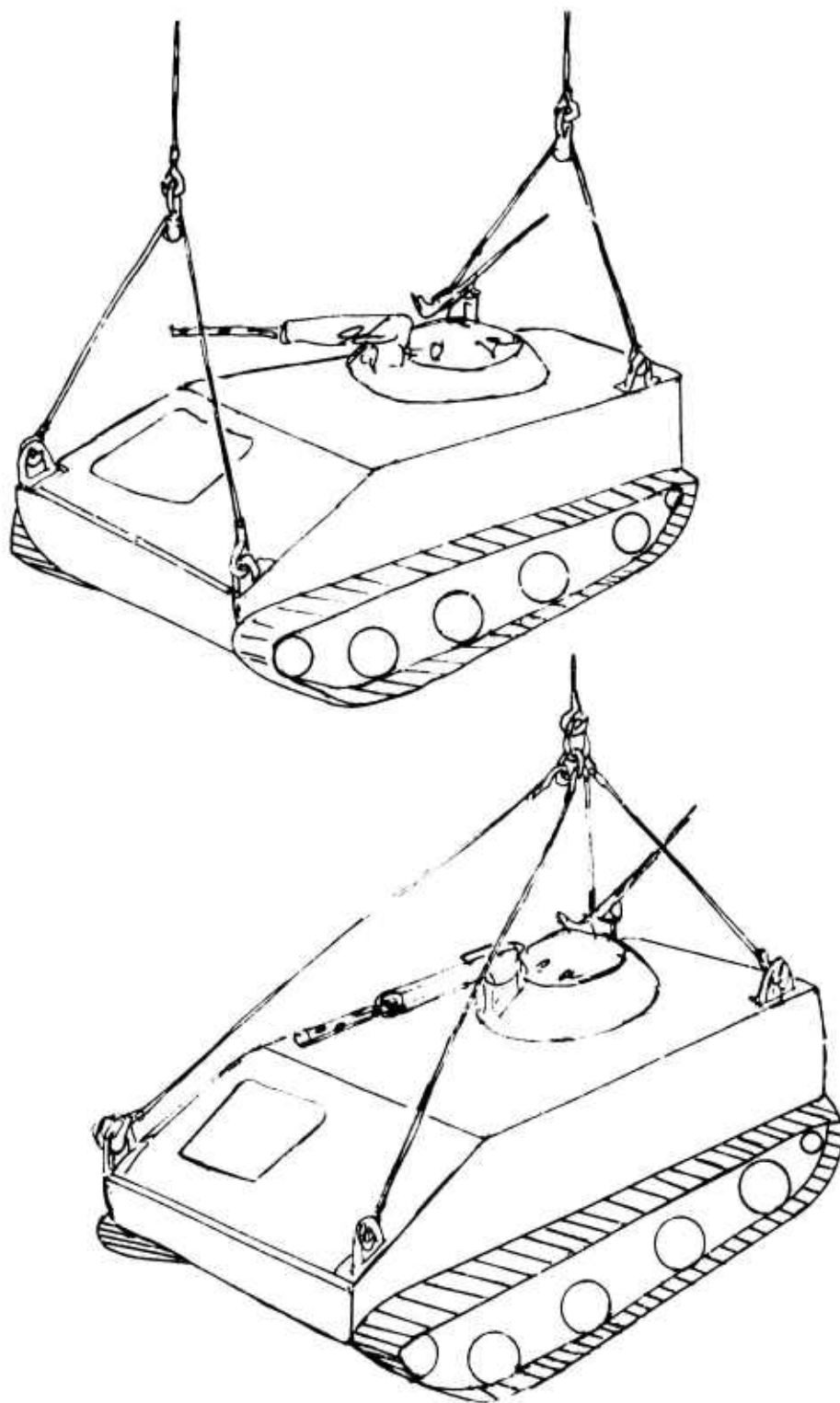


Figure 3. Typical Tank-Hoisting Slings.

In commercial maritime operations, only containerized cargo in shore operations has been automated extensively. The lifting frame and load must have no relative movement and must be clearly visible to the crane operator. It is then possible to lower the lifting frame to almost perfect alignment with the load with no manual assistance.

Helicopter and commercial maritime load handling operations are comparably similar. They differ primarily in the inherently nonstatic state of the frame to load relation. To dispense with the services of the ground crewman, the key feature of most engagement techniques, is the objective of this review of advanced load engagement technology.

Ideally, an automatic load engagement system would consist of a helicopter-based device capable of mechanically duplicating the functions currently performed by the ground crewman. To support this contention, several pertinent cases of current technology of automatic engagement of large physical objects were scrutinized.

#### Deep Ocean Work and Rescue Systems

Development of most automated work devices in the area of deep ocean work and rescue systems has occurred within the last decade, prompted by:

1. Commercial ocean mining and drilling operations .
2. The Navy's interest in rescue vehicles to retrieve sunken submarines, etc.
3. Intensified scientific interest in oceanography.

Deep ocean systems fall in two categories:

1. Manned, free-swimming vehicles.
2. Remote-controlled vehicles tethered to a surface ship.

Free-swimming vehicles are used primarily for exploration of the ocean floor, marine life research, as well as several Navy search operations. A typical example is the ALVIN.

ALVIN (Figure 4), built for the Office of Naval Research, is a 6000-foot-depth submarine-type vehicle equipped with an articulated manipulator, sonar, and high-intensity light. Four large portholes on the bow provide for observation of the work site and for control of the manipulator.

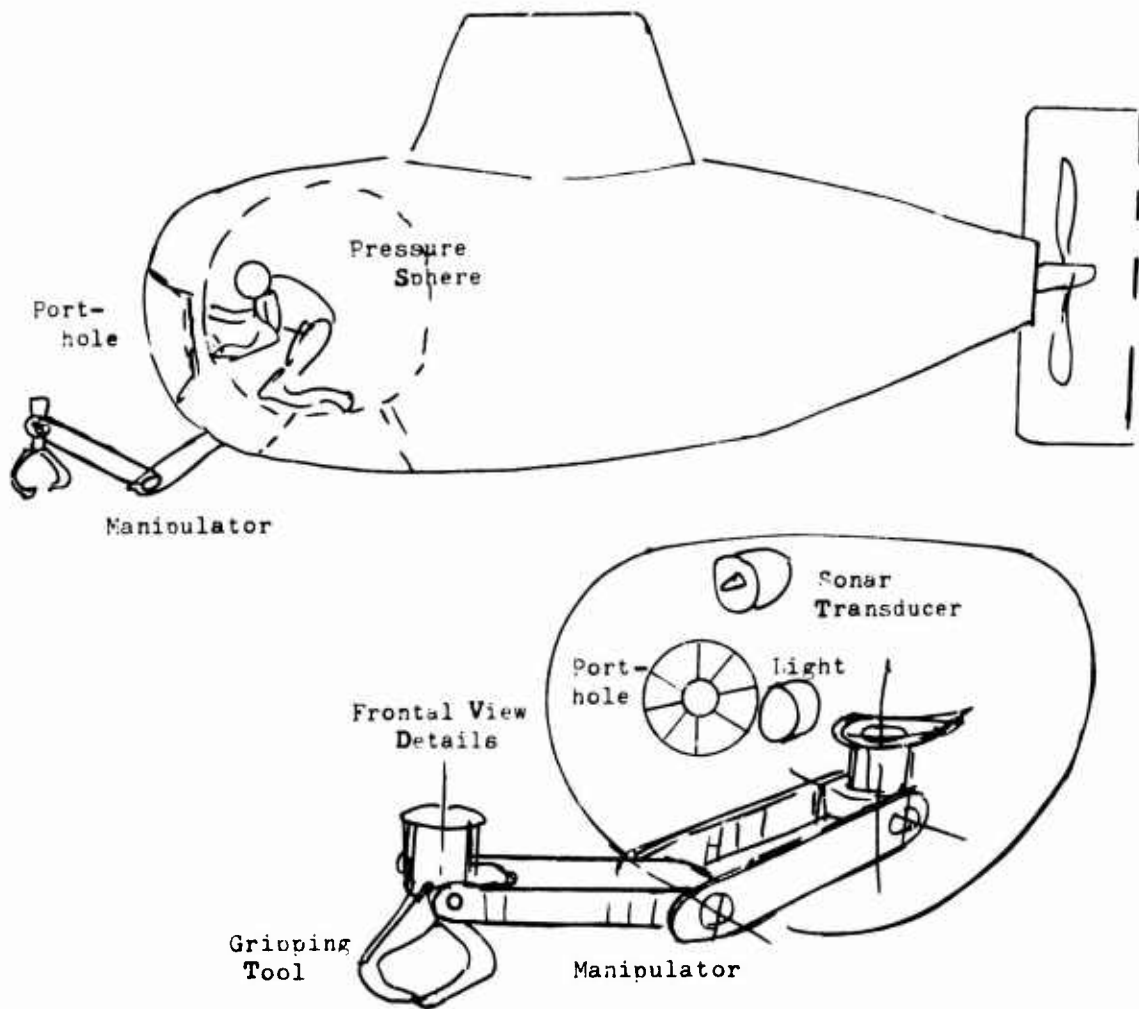


Figure 4. Schematic of ALVIN, Showing the Manipulator.

The operator sits in a pressure sphere behind the viewing portholes. The manipulator is a carry-over from a nuclear "hot cell" manipulator. The articulated arm is powered by electric DC motors through gear trains and controlled by switches on a portable control box. Experience with ALVIN indicated that two manipulators would be an improvement: one to hold the work and the other to perform the work.

BEAVER (Figure 5) has two hydraulic work power tools (arms) and two positioning arms that work with an anchor to hold the vehicle in position during job performance. From a folded position, the manipulator can reach within a 6-foot radius approximating human articulation. Piston-driven rack and pinion actuators actuate pivot points. The control box (on the surface ship) is arranged to provide a spatial correspondence between the operator's hand motions and those of the tool in the manipulator.

CURV, developed and operated by Naval Ordnance Test Station, Pasadena, California, has been used for salvage and tethering of sunken ships, as well as underwater cable inspection and oceanographic research. CURV has one work manipulator of simple design, capable of partial articulation and extension of up to 10 feet. The actuation system is mainly hydraulic. The primary work tool is a pair of forceps-like claws.

#### Electromagnetic Engagement of the Load

Ferrous material handling equipment employs electromagnets. Such equipment could be utilized in handling boxes or containers appropriately reinforced and outfitted with a ferrous lifting side. Electromagnetic pads are suspended from a load spreader-like platform which harbors the necessary electrical equipment for servicing the electromagnets.

### 2.3 AEROSPACE LOAD HANDLING DEVICES AND TECHNIQUES

#### The Astrotug

The Astrotug is a space work vehicle equipped with an assortment of tools for performance of tasks in assembly, maintenance and repair of space stations. The vehicle has a throttleable propulsion system for maneuvering, and instrumentation for navigation and rendezvous with a space station. A set of four remotely controlled manipulator arms is provided at each end of the cylindrical body of the vehicle. The manipulators are controlled remotely by the crew in two work stations inside the cylinder. The controls consist of a scaled model of each manipulator arm in its proper position. Movement of the model arm by the operator is exactly repeated, through a servo loop, by the external manipulator arm. The



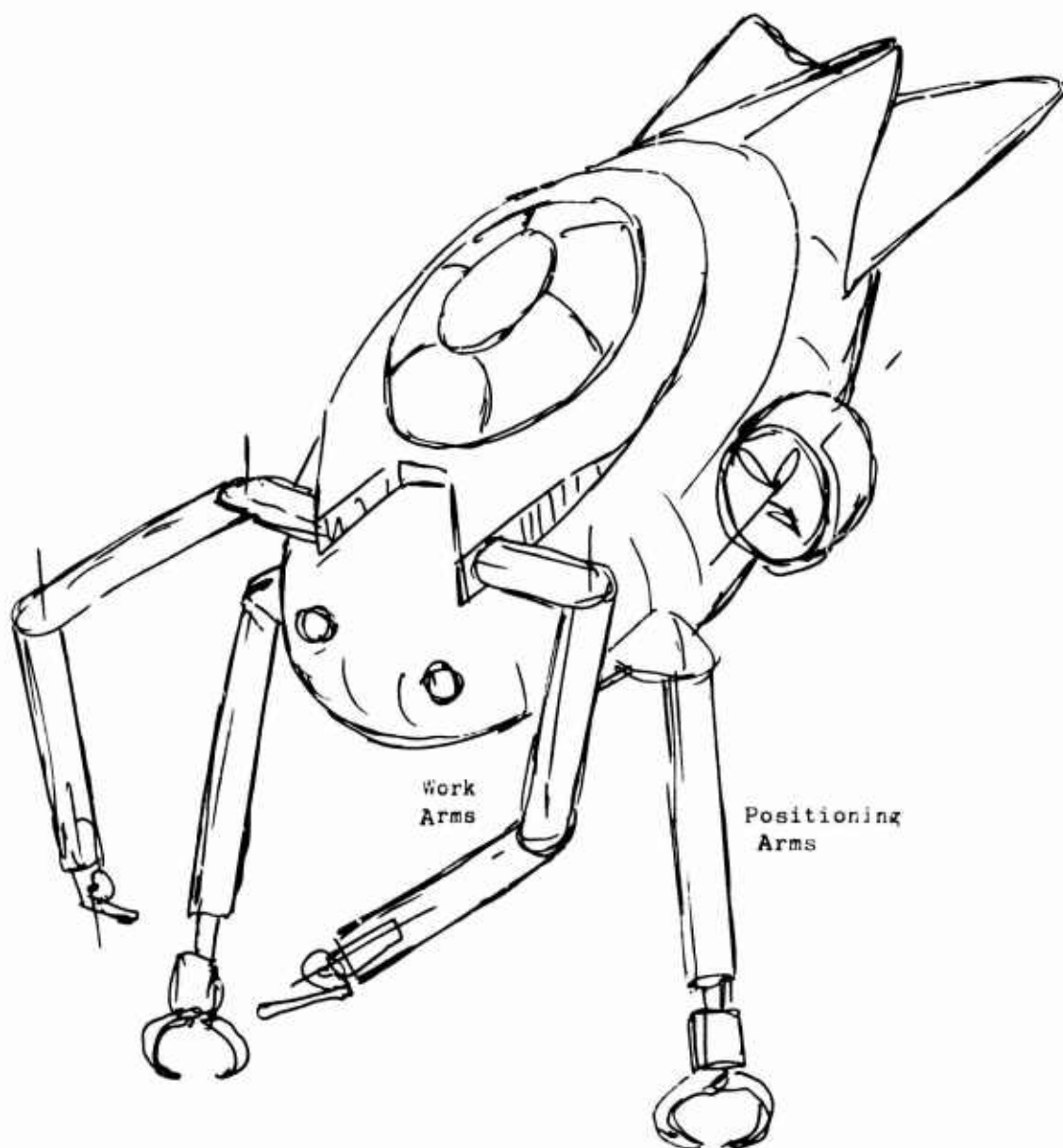


Figure 5. BEAVER Remotely Controlled Work System.

arms are powered by electric motors. The arms can handle a variety of tools and can move lights and TV cameras into position for close observation of the work site.

### The Mobot

The Mobot is an unmanned vehicle for maintenance and repair of space vehicles. The vehicle can be cable controlled from a command vehicle or radio controlled without any tethering line. The "Mobot" manipulator arm can perform a variety of complex tasks, such as adjusting controls and operating power tools. After a learning period, an experienced human operator of the mobot would become unaware of the controls linking him to the machine and would identify himself with the mobot. Such identification would result in the most efficient utilization of the manipulator potential.

### Manipulator Analysis

An anthropomorphic manipulator should duplicate most motions possible to the human hand. In addition, it may be required to have tactile sensors for handling delicate objects. Complexity of the manipulator design resulting from attempts to approximate the functions of a hand can become overwhelming. Fortunately, many manipulator machines, other than prostheses, are designed to fill a specific need in load handling operations, and the functions the manipulator is asked to perform are limited to only a few.

## 2.4 CURRENT TECHNOLOGY FOR HELICOPTER EXTERNAL LOAD HANDLING

A review of the current methods for handling helicopter external loads has shown this process to be strongly dependent on manual-aid and highly nonstandardized load handling equipment and techniques. Typical load handling equipment and techniques necessary for preparation of Army aircraft and helicopters for lifting by a helicopter are described in Reference 1. The engagement of Army aircraft for lifting, as presented there, is based on the "bellyband slinging" concept. Each type of aircraft, in this concept, requires a different set of slings. The sling and straps are made of reinforced nylon ropes. Straps are also used for safe-tying various elements on the load.

A light airplane is prepared with two slings under the fuselage at locations in front and aft of the wing. The slings are brought to a spanwise spreader bar. The lengths of the sling lines are calculated to make the lifting force of the

1. Huebner, W. E., AERIAL RECOVERY KIT, Technical Report 68-2, Sikorsky Aircraft, June 1968.

lines pass approximately through the center of gravity. The propeller is secured against rotation and the wings are fitted with spoilers to reduce the lift generated in flight to a negligible level. A drogue chute is attached at the tail for stabilization in flight. Various positioning straps are also necessary for the slings. The spreader bar would lie on the top of the fuselage at the time of manual attachment of the lifting line.

A typical twin-engine type airplane is prepared with slings in a similar manner. Here the belly slings are brought to a chord-wise spreader bar. The lifting "eye" is equipped with a pulley which rides on the short spreader line for self-adjustment to the airplane center of gravity. Propellers are secured with straps, wings are fitted with spoilers, and control surfaces are secured against movement. A drogue chute is attached for stability.

A light Army helicopter is prepared with slings under the belly in a manner similar to the airplanes. An alternative method of suspension is by the rotor blades at the hub. In either case, the main rotor is secured to the tail cone and to the skids with nylon straps. The tail rotor is also secured. Slings have to be of proper length to assure that the lifting force passes through the helicopter center of gravity. A weathercocking chute is again attached for stability.

A tandem-rotor Army helicopter is prepared with long slings under the belly. Positioning straps for the slings make the sling bearing points stay in the prescribed locations. Two spreader bars are used for this aircraft, corresponding to the forward and aft slings. For handling this type of helicopter, the rotors are removed from the craft. A minor dismantling of the helicopter body is also necessary for a proper accommodation of the sling lines.

In all cases the crewman has to climb on the top of the craft to engage the lifting line hanging down from the lifting helicopter to the lifting "eye" on the sling harness. An assortment of slings and straps tailored to each type of aircraft together with some auxiliary equipment is packaged into a special container. The package is called "the aerial recovery kit". The kit would be carried to the site of the craft to be transported together with a ground crew of about six men. The packing and unpacking of the container would take about 10 minutes. A considerably longer time would have to be allowed for actual preparation of the craft to be airlifted.

The concept and hardware of the aerial recovery kit reflect a careful study which has gone into the problem of load preparation for aerial transport by helicopter. A concern in the

design of the kit for load preparation has been along two lines: (1) to prevent any structural damage to the craft to be airlifted which might be incurred during air transportation, and (2) to prevent the load from adversely affecting the flying qualities of the lifting helicopter while in transfer.

Specific attention was given to the following items in load/aircraft preparation:

1. Immobilizing of propellers or rotors.
2. Immobilizing flight controls and lifting surfaces such that no undesirable motion could be excited during flight.
3. Positioning of sling straps for best structural load distribution.
4. Prevention of load swinging or unstable gyration in flight.

## 2.5 APPLICABILITY TO CONTRACT OBJECTIVES

The results of the survey of current technology in cargo handling indicated that:

1. Due to the large variety of load types, configurations and lifting provisions, numerous types of handling equipment are required in the cargo handling operation.
2. Except for the handling of container loads, the hookup and hoisting procedures are entirely manual.
3. The designs of the lifting provisions on various types of helicopter external loads are highly non-standardized.
4. Most of the current technology and equipment are not directly suitable for use in automated load acquisition.
5. Innovative approaches are needed to achieve the design of a simple and versatile automated load acquisition system.

### 3.0 CATEGORIZATION OF HELICOPTER LOADS AND ANALYSIS OF LIFTING PROVISIONS

#### Categorization of Helicopter External Loads

Based on the load data obtained from the transportability guidance manual, the loads are categorized in the following major groups: (1) logistics, (2) combat loads, (3) combat support, (4) aircraft, (5) helicopters, and (6) special loads. Load configurations and lifting provisions of typical Army loads are identified and categorized. The present technology in handling such loads and the equipment required to lift them are also presented. The grouping and categorization of various helicopter external loads are made based on their commonality in operational load types, load weight, configuration, air transportability, and lifting provisions. Helicopter external loads are categorized as follows:

#### GROUP 1 - Logistics

1. Container
  - Conex
  - Milvan 8' x 8' x 20'
  - 8' x 8' x 40'
  - Racks & Gondolas
  - Pallets
2. Crane
  - 5-Ton Crane
  - Wheel-Mounted 20-Ton Crane
3. Scraper
  - Towed, Earth-Moving Scraper
4. Tanker
  - M559 Tanker
5. Shovel
  - Truck-Mounted 20-Ton Crane-Shovel

#### GROUP 2 - Combat Loads

1. Armored Recon Airborne-Assault Vehicle
  - M551
2. Armored Track Carrier
  - M113
3. Tracked Self-Propelled Howitzer
  - M110

4. Self-Propelled Field Artillery Gun  
M107

5. Tracked Mortar Carrier  
M125  
M106

6. Missile  
Surface-to-Air  
Chaparral  
HAWK  
NIKE Hercules  
SAM-D  
Battlefield Support  
Lance  
Honest John  
Pershing  
Sergeant

7. Field Artillery  
Howitzer  
Rocket Launcher

GROUP 3 - Combat Support

1. Tracked Cargo Carrier  
M548

2. Truck  
M35, 2½-Ton, 6x6  
M220, 2½-Ton, 6x6  
M215  
M55, 5-Ton, 6x6  
M123, 10-Ton, 6x6

3. Semitrailer, Van  
M128, 12-Ton Cargo Van  
M127, Semitrailer  
M270, Low-Bed Wrecker  
M118, 6-Ton, 2-Wheel Stake

GROUP 4 - Aircraft

Observation Aircraft O-1G, Bird Dog  
Observation Aircraft OV-10, Mohawk  
Training, T-42A, Cochise  
Utility, U-1A, Otter  
" U-6A, Beaver  
" U-8D, Seminole  
" U-21, Ute

## GROUP 5 - Helicopters

OH-13, Sioux  
OH-58, Kiowa  
UH-1, Iroquois  
OH-6A, Cayuse  
TH-55, Osage  
AH-1, Cobra  
UH-19, Chickasaw  
CH-53, Tarhe  
CH-47, Chinook

## GROUP 6 - Special

1. Bridge Section  
CL 60, AVLB Bridge  
Ferry Bridge Section
2. Construction Material  
Landing Strip Plates  
Poles  
Prefabricated Walls

Information gathered and analyses made on the helicopter external loads and their grouping were used for:

1. Providing the design guide for configuring the automatic load acquisition system.
2. Establishing the system requirements for automatic load handling operation.
3. Evaluating the versatility of various HALAS designs in handling different load types.

### Analysis of Lifting Provisions

The purposes for analyzing the lifting provisions of various loads are:

1. To examine the adaptability of the existing lifting provisions for automated load acquisition.
2. To determine the appropriate acquisition device for automatic hookup.
3. To optimize the HALAS design for handling many types of loads.

The characteristics of typical Army helicopter loads and the design configuration of their lifting provisions are presented

in Tables A-1 through A-4 of Appendix A.

The results of the analysis indicated that the lifting provisions of various loads are highly nonstandardized even for loads in the same group and category. The data also indicated that some loads have no provisions at all for airlifting. It is to be noted that the design configurations of most of the lifting provisions shown are not suitable for automatic load acquisition by helicopter. The rear lifting provisions of practically all Army trucks are well hidden under the truck bed, which is obscured when viewed from above the load. In all the truck designs, the rear lifting provisions are well recessed between the dual rear tires of the truck, making it inaccessible from the top and not easily accessible from the sides of the truck. This major Army load is not easily adaptable to automated load acquisition without modifying the lifting provision or attaching other lifting provisions in preparing the loads for automatic acquisition.

Due to the nonstandardization and inadequacies of the lifting provisions on most of the Army load types, a HALAS system to handle prepared loads will be more feasible and practical than a system to handle completely unprepared loads.



#### 4.0 ESTABLISHMENT OF ARMY AIR TRANSPORTABILITY REQUIREMENTS

##### Introduction

In order to formulate and develop an effective automatic external load acquisition system for the Army helicopters, the Army air transportability requirements are to be established, applicable to both current and future helicopters with external load handling capabilities. The Army air transportability requirements were analyzed for the purpose of identifying those critical operational and technical areas where external load acquisition problems exist and where future problems are anticipated. Automatic load acquisition capability includes the identification of guidance and positioning information during helicopter terminal approach, hover, station-keeping, load acquisition, and departure under various flight conditions such as rain, fog, snow, blowing dust, and other IFR conditions when the target load is not visible to the pilot.

#### 4.1 TYPICAL SCENARIO FOR HELICOPTER LOAD TRANSPORTATION MISSION

##### Ground Point-To-Point Load Airlift

The load pickup area is, in general, away from the helicopter staging depot. In the helicopter airlift system, four interface functionaries are assumed:

1. Transportation Officer (T.O.). He is cognizant of load staging areas, their geographic locations, and inventory status. He responds to requests from Army units or an Army command. He issues transportation orders.
2. Dispatching Officer (D.O.). He is responsible for the activity of a fleet of cargo helicopters; he is cognizant of the type, performance, and lifting capabilities of the helicopters in the fleet; he is cognizant of the current location, mission scheduling, and active status of the cargo helicopters. He selects the helicopter for the load order, and assigns the crew and auxiliary lifting aids. He contacts the officer responsible for the load pickup area, determines the exact location of the load within the pickup area, checks for landmarks, requests identifying markings or landing aids, and checks the weather and visibility conditions. He issues mission orders.

3. Lifting Officer (L.O.). He is in command of the cargo helicopter. He accepts the mission orders and verbal instructions pertinent to the load lifting mission. He procures a description of the load and an isometric drawing or three-view drawing. He decides on the lifting provisions either available on the load or needed to be put on. He decides on the type of lifting devices and equipment to carry. He may request a support helicopter to carry equipment for load preparation. He plans the mission for optimal trade-off of the mission time, safety and air transportability.

He requests special aids equipment for load acquisition in IFR conditions. He operates the lifting devices, hookup devices, etc., for attachment to the load; he controls the cargo helicopter over the load and during acquisition. He gives flying orders to the helicopter pilot.

4. Helicopter Pilot (H.P.). He flies the helicopter between the destination points.

### Mission

The T.O. issues orders for load pickup from an Army depot X. Orders contain load description, its location, destination, and time limit.

The D.O. accepts the order. He identifies the load in the load handbook. On the mission order he fills in the details of weight, c.g. position, and load group category. This allows him to select or match the cargo helicopter. He may assign the lifting aids or let the L.O. decide on what is needed. He calls the pickup area officer and verifies the load. He makes a preliminary check of the flying and pickup conditions and makes a recommendation on the mission order. He checks the schedule list for the assignment. He selects the helicopter of the proper capability and time availability. Generally, the mission orders are issued daily; in emergency cases the D.O. will identify the helicopter operating in the location nearest the pickup area and issue the mission change order by two-way radio. A recorder on board the cargo helicopter will be turned on for future verification. He gives the mission orders to the L.O. of the selected cargo helicopter.

The L.O. accepts the mission order. He verifies the description and recommendations of the D.O. and makes the mission plan. He examines the volume, weight, and

lifting characteristics of the load by reference to the L.O. handbook, which will contain recommended lifting and load acquisition hints for most of the standard type loads. The L.O. may, at his option, select a different procedure. Once the L.O. has decided on the mission plan, he requests and procures such necessary aids as lights, electronic aids and optical/electronic acquisition and identification aids. He decides on the method of lifting and procures the necessary devices, including aero stabilization devices. If the load has no lifting provisions, but is one of the standard loads, recommended load preparation is described. The L.O. then contacts the D.O. and asks that an advanced party be dispatched with load preparation gear. He estimates his helicopter takeoff time and contacts his H.P.

The H.P. checks the weather, maps the fastest route, and makes the flight plan. He is responsible for the helicopter flight performance. At the time of lift-off, the L.O. checks all items of equipment he requested and which have been either put on board or attached to the helicopter by his ground crew. Getting to the load area, the H.P. uses either VFR or IFR, or any other advanced area navigation systems within the equipment capability of the helicopter.

It is assumed here that all load staging areas have nucleus crews who are aware of the load pickup mission. These crews would be equipped with two-way radios for terminal assistance in load acquisition. This will be universally assumed for load acquisition of all kinds with the exception of emergency pickup missions of people in distress either on land or sea or important pieces of military hardware which have been deserted by their keepers. Such missions present a separate problem of load identification which may require sophisticated detection gear and procedures.

Acquisition of the loads in nonemergency conditions is aided by directions over two-way radio, if necessary, and therefore presents no major problem even in adverse weather conditions.

The loads to be picked up must (1) be in an open area with no vertical obstacles taller than 50 feet and (2) be isolated from other loads sufficiently for the pickup equipment to be attached. These conditions cannot be relaxed for obvious safety reasons. The L.O., on finding the situation otherwise, will abort the airlift mission.

With the helicopter over the load, the load acquisition phase begins. At an altitude of 100 feet, the H.P. transfers the controls to the L.O. The L.O. has the view of the load either directly or on closed-circuit TV display or both. The L.O. will control the helicopter altitude and position over the load; the area illuminating lights; observation points of TV cameras; and most important, the lowering, engagement, and attachment of lines, frames or any other load engagement devices. If he uses the manipulator, he will control the manipulator operation through a remote control supervisory control grip.

For load pickup from the ground, the helicopter automatic stabilization will keep the helicopter station stable relative to the ground. For load pickup from a ship, additional sophistication will have to be added to the stability equipment. Attitude motions of the ship relative to the local level will be sensed with the ship's stable platform or autopilot gyros and the motion signals transmitted to the helicopter stability and control coupler. These signals will keep the helicopter stable relative to the ship's deck. All other load acquisition procedures will be the same as for the ground-based load.

#### 4.2 TERMINAL APPROACH AND LOAD ACQUISITION CONSIDERATIONS

Air transportability requirements for a helicopter automatic load acquisition system (HALAS) arise from the proposed system operational needs to achieve the desired performance; the performance objective of the system is broadly defined as the nonmanual acquisition of externally located loads for airborne transfer.

The mission operations can be divided into four major parts:

##### 1. Preflight

Issuance of mission orders including description of the load, its geographic location, and required time schedule for transfer.

Association of the load with one of the identifiable load groups for the proper helicopter assignment.

Load preparation for automatic handling by local ground crews or crews dispatched to the load area by other means of conveyance.

Flight planning including navigational aids, guidance aids, terminal area weather, visibility, time of day, and other environmental conditions.

Requisition of load acquisition kit and any other foreseeable aids aimed at expediting the mission and reducing the mission time needed for acquisition.

2. Enroute

Airborne flight carrying, either internally or externally, the load acquisition gear.

Engagement of standard navigational aids.

3. Load Area Operations

A sequence of activities leading to load engagement and lift-off (which shall be expanded below).

4. Departure

Capability to fly away with the load.

Load Area Operations

The load area operations consist of:

1. Guidance and control of the load within the load area (where load area is defined here as some area or positions corresponding to a navigational accuracy).
2. Load recognition and alignment; this includes identification of the load pickup provisions and their locations.
3. Hover/station-keeping in adverse weather or sea-state conditions.
4. Lowering of the load acquisition devices to position for engagement with the load; this includes the man-in-the-loop control system aided by closed-circuit TV.
5. Load lift-off and fly-away departure.

Items 1 and 2 are expanded in the following:

1. Guidance and control of the load within the load area.

### VFR Conditions

In VFR conditions, a visual search of the load area will be sufficient. Loads ready for acquisition have to be moved into areas clear of overhead obstructions.

A single load will be readily recognizable. A pickup of one particular load from a yard of similar loads has to be aided by some form of positive visual identification. Since many load acquisition missions will be of this nature, rules for the proper operations have to be outlined.

The presence of cooperating ground crew at the load area will streamline the operation and reduce time waste. It appears that a requirement for such presence will be met in most actual situations automatically; some emergency situations will have to be treated separately. Transfer of loads will be prearranged between units of a broader transportation command.

At least one member of the yard or depot unit will be cognizant of the load transfer mission, with particulars of load type and its exact location within the yard. Such individual will, using two-way radiotelephone, direct the helicopter to the load. If the yard is the deck of a ship, voice instructions will be sufficient for the terminal guidance.

In VFR nighttime conditions, the two-way radiotelephone support may be combined with searchlights of the helicopter. The general procedure for night operations will be: (1) to arrive at the load area several hundred feet above the terrain or ship enough for the searchlight to illuminate the whole of the possible load area; (2) after a visual load identification aided by the ground-based directions, to descend to position over the correct load.

If visible searchlights are not allowed because of the combat zone, the area may be illuminated by invisible infrared radiation or millimeter microwaves. Suitable receivers will be able to detect the load outlines. The load identification and terminal guidance requiring no help from the ground crew would follow the procedure as used under IFR conditions.

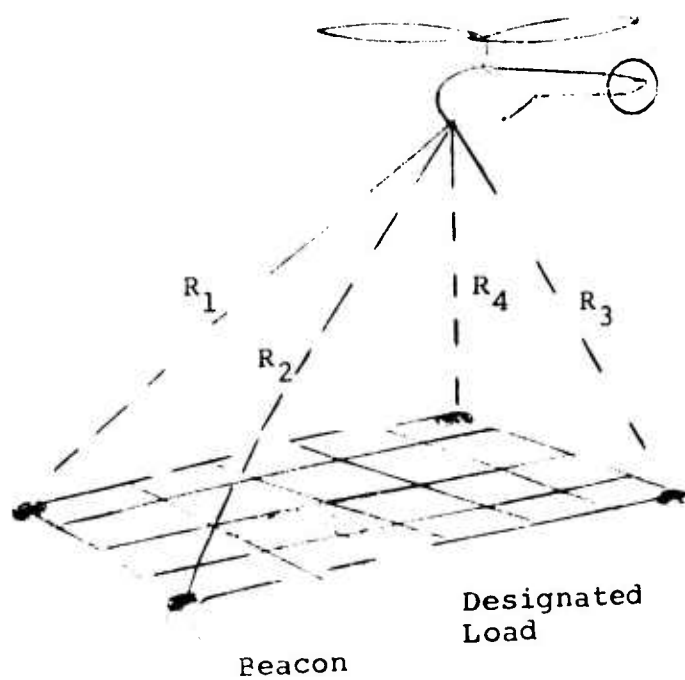
### IFR Conditions

Load acquisition under IFR conditions requires more complex preparation of the load area for the purpose of load identification and homing.

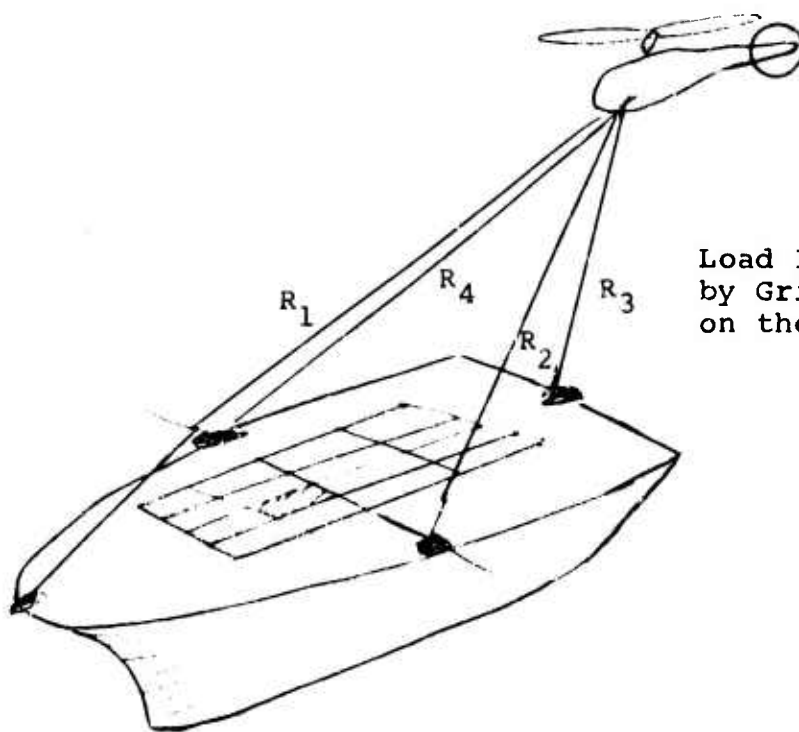
Loads such as containers, or any other loads which can fit into a geometric grid pattern, can be bounded by four corners of a rectangular area with four beacons or beacon/transponders. The spacing of the grid lines in two dimensions could either be known from the flight orders or conveyed to the helicopter by the ground crew. The particular load would then be identified by some x, y coordinates within the grid bounds. Such a system application is illustrated in Figure 6. The actual location of the load would then be computed on-board and the positioning guidance commands derived from the position errors. Once over the load, the descent guidance would use a simple algorithm relating the distances of the transponders and the height above the load for descent guidance along the local vertical at the load.

The beacons or transponders will have their signals coded for proper identification. One form of semi-automatic guidance would consist of guidance error signals displayed to the pilot for his corrective action. On arrival over the load and adjustment of the hover clearance to the load, the pilot would switch over to the automatic hover/station-keeping control system. The beacon signals could be used as the source of a stable position reference.

At the time of the load acquisition, the load officer would adjust the helicopter position by adjustment of the error signal biases driving the position control loops. Station-keeping hover stability will be provided by the automatic attitude control system. Figure 7 illustrates the station-keeping and descent system for load acquisition.



Load Identification  
by Grid Coordinates  
in the Load Yard



Load Identification  
by Grid Coordinates  
on the Ship's Deck

Figure 6. Load Identification by Grid Coordinates.



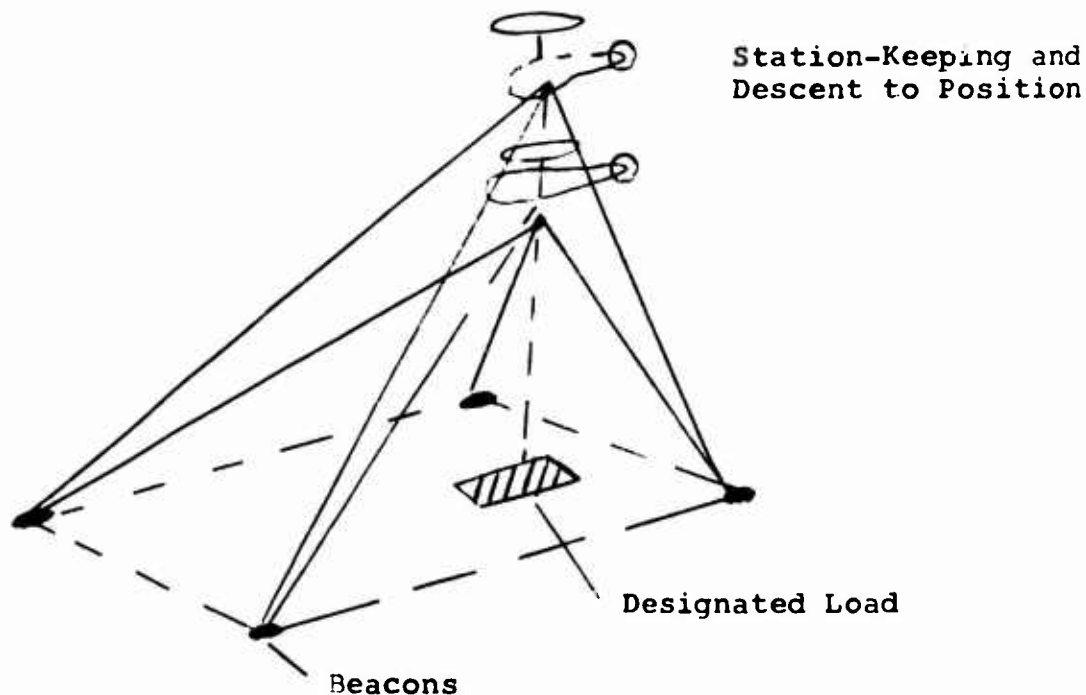


Figure 7. Descent to Position for Load Acquisition.

## 2. Load Recognition and Alignment

### VFR Conditions

Once the helicopter is in the hover position for load acquisition, the pilot or load officer has to verify the load by inspection, and has to align the helicopter to the load reference line. The altitude of the acquisition or hover/station-keeping will depend on the local ground conditions. It should be high enough to clear obstruction and low enough for control of the engagement/acquisition devices. An important task of load recognition is identification of the lifting pickup provisions. The load officer will be aided in this task by either a reference manual listing standard Army loads or by the descriptions given in the transportation orders.

### IFR Conditions

In IFR and low visibility conditions, both the load recognition and pickup provisions identification will not be possible directly.

Alignment with the load and station-keeping for acquisition will not be affected by visibility conditions since these functions can rely on the microwave aids.

An important assumption will be made at this point. The visibility limitations, as described by such ratings as FAA Cat 3 a,b,c, will admit visibility at close ranges of some 10 feet or less, and similarly for visibility reduced by snow, rain, dust or sand. Therefore, image-sensing devices, when placed within 10 feet or less of the load, should be capable of examining the load and of identifying the lifting pickup provisions. In the present approach to the acquisition system, closed-circuit TV cameras are placed on selected acquisition devices for the purpose of (1) inspection of the load and (2) engagement of the acquisition devices using remote viewing.

TV receiver display on-board will be used by the load officer in the control of the helicopter and acquisition devices for engagement and lock-on.

### 4.3 CONSIDERATIONS FOR ESTABLISHING THE ARMY AIR TRANSPORTABILITY REQUIREMENTS

#### Critical Operational and Technical Areas of the HALAS

In general, terminal operations are the only areas where new procedures, sensors, and displays have to be provided. The difficulties stem from:

1. Low lighting and visibility conditions at the terminal area.
2. Load acquisition and engagement by on-board means in the above visibility conditions.
3. Remotely controlled engagement means and two-dimensional viewing of the three-dimensional engagement process.
4. Station-keeping and control of the load acquisition device for load acquisition from platforms experiencing six degrees of freedom motion.

### Hover/Station-Keeping Over the Land-Based Station

The helicopter stabilization-control system will provide sufficient attitude stability in hover/station-keeping during the load acquisition. Maintenance of the position over the load will require visual cues which are used by the pilot or load officer for comparison with the desired position; the position errors are then reduced manually. In low visibility and adverse weather conditions with wind, keeping of the helicopter over the station will require position information of the reference station. Such information could be supplied to the helicopter by one or more station-based beacons. The beacon signals would then be used as an indication of the load position (single-fixed beacon) or as a means for computation of the current helicopter position relative to the desired position. The error signals would then be used for either manual or automatic position correction.

### Hover/Station-Keeping in Sea-State Conditions

Load acquisition from the deck of a ship presents a new problem: it is the deck of a ship that rolls and pitches relative to the local-level-stabilized attitude system.

A load on the deck of a ship will present the following conditions: (1) attitude motions of the load in pitch-and-roll, and (2) position motions in three dimensions due to the ship up-and-down motions on the crest of a wave and due to the load offset from the center of the ship's rotation.

In general, load lift-off from a cargo ship will be aided by four beacons or transponders designating a rectangular boundary of the ship's hold. For position station-keeping, signal returns from four beacons will be processed and the desired information about the position over the load extracted therefrom. This data will indicate a line normal to the ship's deck and passing through the particular load.

Considering now the motion of the deck, the intersection point of the normal line at the load will move with the deck, producing motion in the horizontal plane depending on the distance from the ship's center of rotation (metacenter).

Thus, for an efficient load acquisition process, the acquisition devices must be: (1) stabilized relative to the ship's deck, (2) have compensations for horizontal second vertical motions (if significant) due to the deck elevation above the ship's center of rotation, and (3) have compensation for the ship's vertical motions due to riding parallel to the wave crest.

One proposed approach to the compensation would use the range information from the helicopter to the four beacons on the ship. Angular motions of the deck can be computed and referred to the local level attitude system available on board the helicopter. Knowing the instantaneous attitude of the deck in roll and pitch, the required resonant attitude changes of the load acquisition device can be established. The required motions in the horizontal and vertical planes can also be determined by calculation. In this manner the load acquisition device will be stabilized to the load on the ship's deck, the resonant attitude motions generated by the load device attitude control system, and the compensating horizontal repositioning by movements of the helicopter while in hover/station-keeping, as shown in Figure 8.

Alternatively, a direct data link from the ship's stable platform could supply the attitude error signals for locking the load device attitude control system to the ship's motions.

#### General Accuracy Requirements for the Acquisition Process

The accuracies required of the helicopter station-keeping during acquisition of the load must be high enough to permit proper engagement of the load acquisition device.

The relative position errors are due to:

1. The system errors (mostly of bias type).
2. Random dynamic disturbances.
3. Random relative motion (Brownian motion type).

Such motions will interfere with the engagement of the load acquisition device and prolong the engagement process. To expedite the engagement, at least two approaches appear open.

1. To provide the engagement mating elements tolerant to large relative motions.
2. To provide a temporary connection between the acquisition device and the load which may eliminate or attenuate all the relative errors, and particularly the random type.

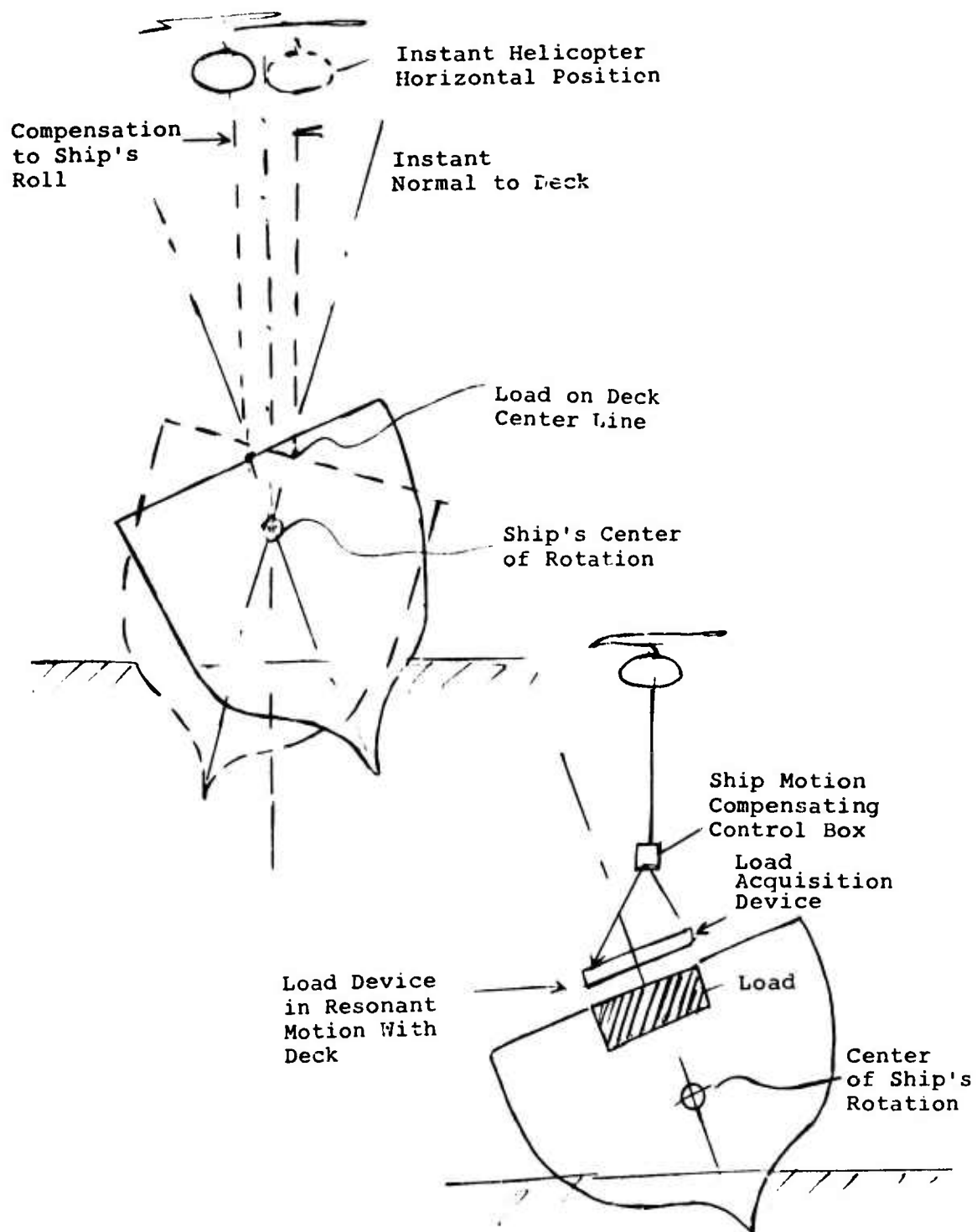


Figure 8. Stabilization of Load Device to the Ship's Deck.

### Positioning Accuracy

Positioning of the helicopter in a station above the load will require accuracies depending on the type of the load and the acquisition device used. For example, engagement of the containers, as currently practiced in shore-based semiautomatic maritime operations, requires almost no errors in placement of the lifting frame on the container.

For the terminal guidance to the acquisition station above the load, the accuracy must be of the order of half the size of the load or better. Otherwise, a wrong load might be acquired. If the smaller size of a general rectangular load is 8 feet, the guidance accuracy must be about 4 feet at the load, or better.

Angular alignment is a part of the load acquisition problem and is governed by the linear accuracy required for the load engagement. An azimuth alignment prior to the acquisition operation and at the end of the terminal guidance phase has to be within small angles - 10 degrees or less. Thus, positioning/station-keeping accuracies of the helicopter above the load should be such as to result in the relative separation of the mating elements (for engagement) of not more than 4 feet (rms).

Vernier position adjustment of the acquisition device relative to the load will be required for some type of engagement process.

### Load Engagement Devices

From the review of the air transportability mission, it is evident that a detailed planning of the operation will be essential to efficient load transfers. Load preparation for lift-off will be a part of such planning. Preparation of the load by placement or attachment of the appropriate gear must be optimized not just for the particular load but for the majority of load types which the air mobility service will be required to handle.

Standardization of the lifting gear will be a partial answer to this problem. Simplicity of the gear design, its use, and ease of attachment to the load must be included in this consideration. Ideally, the gear should allow engagement by the helicopter acquisition devices within some margin of position errors, thus eliminating the need for vernier relative position adjustments. Time of the engagement operation should be minimized, with the load preparation time kept reasonably low.

It is important to note that although electronic systems are needed for load identification, station-keeping, and load engagement in low visibility, poor weather, and dynamic loading conditions, the operation of the automatic load acquisition system should not be dependent on complex electronic sensing and control systems. The automatic load acquisition system should be designed to have the capability to achieve load engagement with a dispersion of 1 to 3 feet between the acquisition device and the lifting provision of the load. This provides adequate performance under normal operating conditions. In IFR conditions operating in poor visibility, bad weather, and dynamic loading situations, electronic sensing and control systems could be utilized to achieve the automatic load acquisition with the same performance capability.

#### 4.5 SUMMARY OF ARMY AIR TRANSPORTABILITY REQUIREMENTS

The Army air transportability requirements pertaining to the design of automatic helicopter external load acquisition systems are summarized in the following.

1. The terminal guidance and load positioning system should be able to search, acquire, and guide the helicopter over the loads under all weather conditions such as rain, fog, snow, and blowing dust.
2. The automatic load acquisition system should have the capability to engage the load from the hovering helicopter without depending on the electronic automated station-keeping flight control systems and the complex sensing systems.
3. The automatic load acquisition system should have the versatility for handling all the major Army helicopter loads.
4. The fundamental system design requirements are simplicity in design, low overall system cost, high reliability in operation, and acceptability in logistics. If any attachment to the existing lifting provisions of the loads is required for automatic acquisition, logistic requirements should be carefully examined.
5. The automatic load acquisition system should be operable utilizing the current lifting sling and attachments in airlifting operation of the helicopter external loads.

## 5.0 PRESENTATION OF CONCEPTUAL SYSTEMS

### Introductory Remarks

Based on the results of the survey of current applicable technology and the established system requirements, various automatic load acquisition system concepts were conceived.

The presented concepts were generated with the following major objectives.

1. Maximizing the utilization of current technology developed.
2. Utilizing the existing lifting provisions of the loads without modification.
3. Simplicity in overall system design.
4. Optimizing the system versatility in handling all types of loads.
5. Minimizing operational and logistic problems.

These design objectives are directly in line with the established system requirements. Not all the concepts presented are practical or promising. They are documented for the purpose of identifying the promising approaches, exploring problem areas, and generating more constructive ideas.



## 5.1 ADJUSTABLE LIFTING CAGE CONCEPT

The lifting cage has long been another popular load transfer device used in maritime cargo operations. The lifting cage extends the frame approach upward to contain the vehicle positively on the sides and underneath. Due to its rigidity, the load and the cage swing together when subject to the dynamic flight motions, reducing the load motion in the complex pendulum mode. The disadvantages of the current lifting cage are that the vehicles have to be individually driven into the cage and rolled out of it, and the current device is not adjustable and flexible to handling different types of wheeled vehicles.

The proposed HALAS lifting cage system concept is an adjustable lifting cage system. Here the four lines of cables supporting the frame, as in the telescoping frame system, are replaced with rigid tubular side members hinged at the frame and at the cross beams of the "I" spreader. The hinges will allow the bottom frame to be telescoped around the vehicle wheels. A truss locking feature is provided by diagonal hydraulic jacks between the tubular side members and the "I" spreader cross beams. Once the frame is contracted to the desired size, the jacks are locked to prevent swinging of the load relative to the "I" beam spreader. Adjustment of the "I" beam in the longitudinal direction to conform to the amount of telescoping given to the frame will complete the adjustment of the cage for the particular load to be airlifted. This lifting cage HALAS concept is illustrated in Figure 9.

## 5.2 AUTOMATED SPIDER GEAR/FRAME SYSTEM CONCEPT

Spider gear loading devices have been discussed in Section 2.1 in the review of the current state-of-the-art lifting technology. They are used in dockside loading and unloading of passenger car shipments. The device consists of two arms with curved ends which are placed manually against the lower part of the wheel tire. The curved ends go around the tire treads. The arms of the spider gear could be adjusted and locked around the wheel tire of the vehicle.

With all four tires secured by the spider gear, the vehicle is lifted up by four cables or arms hanging from two broad spreader bars. The broad bars, which are just above the vehicle, are designed to prevent any part of the lifting gear from touching the body of the vehicle.

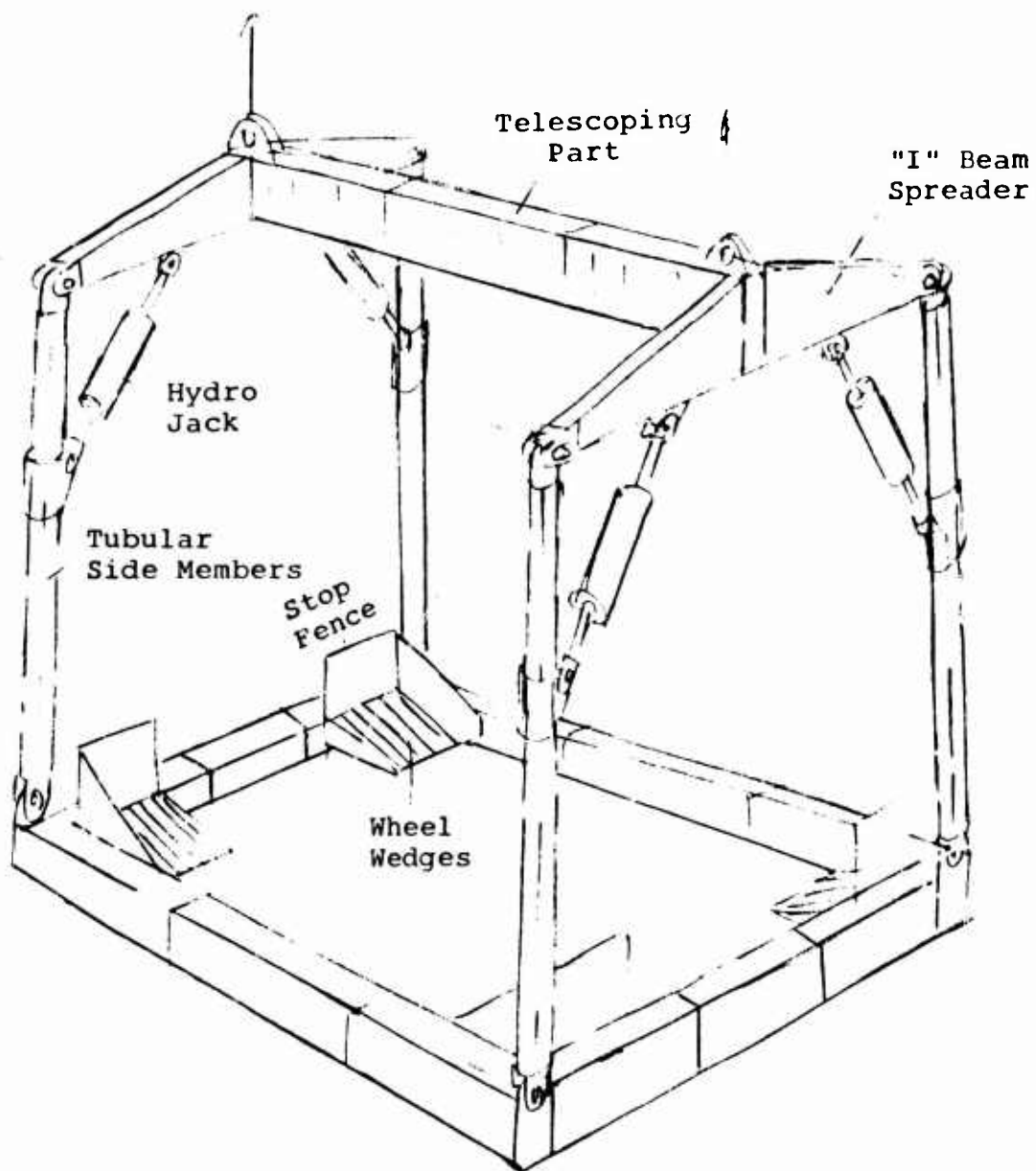


Figure 9. HALAS Adjustable Lifting Cage System Concept.

The spider gear concept permits the whole lifting system to be made light and simple. The low weight of the device and the load locking feature make the concept attractive for the automated approach.

In the automatic version, as shown in Figure 10, the proposed automated spider gear/frame system concept, the most difficult part would be the placement of the spider gear against the tire. In order to accomplish that remotely, four arms suspended and hinged at an "I" type spreader bar are first opened sufficiently to clear the vehicle body. As the fore-and-aft spacing of the cross beams on a telescoping spreader bar are correctly adjusted for the particular load to be airlifted, the arms could then be closed, enabling the gear to grip around the wheel tire.

To accomplish the load engagement, two factors must be present: (1) the "I" spreader bar has to be aligned in the fore-and-aft direction with some reference parts of the vehicle, such as the front and rear bumpers; and (2) the height of the spreader bar above the ground must be correct for the arms of the spider gear to encounter the lower part of the wheel tire.

To perform these two functions, the "I" spreader bar will be capable of telescoping before engagement. The longitudinal "I" beam member will be equipped with caliper type tubular members extending down the proper length, compatible with the spider arm length as shown in Figure 10. The tubular legs will be ended with a foot-like appendage. For load engagement, the whole frame is lowered over the load until the two feet contact the ground. Next the "I" beam position is adjusted to be approximately in the plane of symmetry of the load. As the "I" beam is adjusted for the proper length of the load, this will effectively align the lifting gear with the vehicle wheels.

Further study is required to achieve a simple and effective automatic alignment and engagement procedure for this system concept.

### 5.3 TELESCOPING FRAME CONCEPT

The telescoping frame concept is an attempt to adapt the desirable features of the container frame to handling of other load types. The frame represents a fresh approach to the automatic load acquisition. Since the objective of the automatic system is to dispense with ground crewmen in the engagement operation, it is unnecessary to make the system duplicate man's function, such as placing the sling hooks

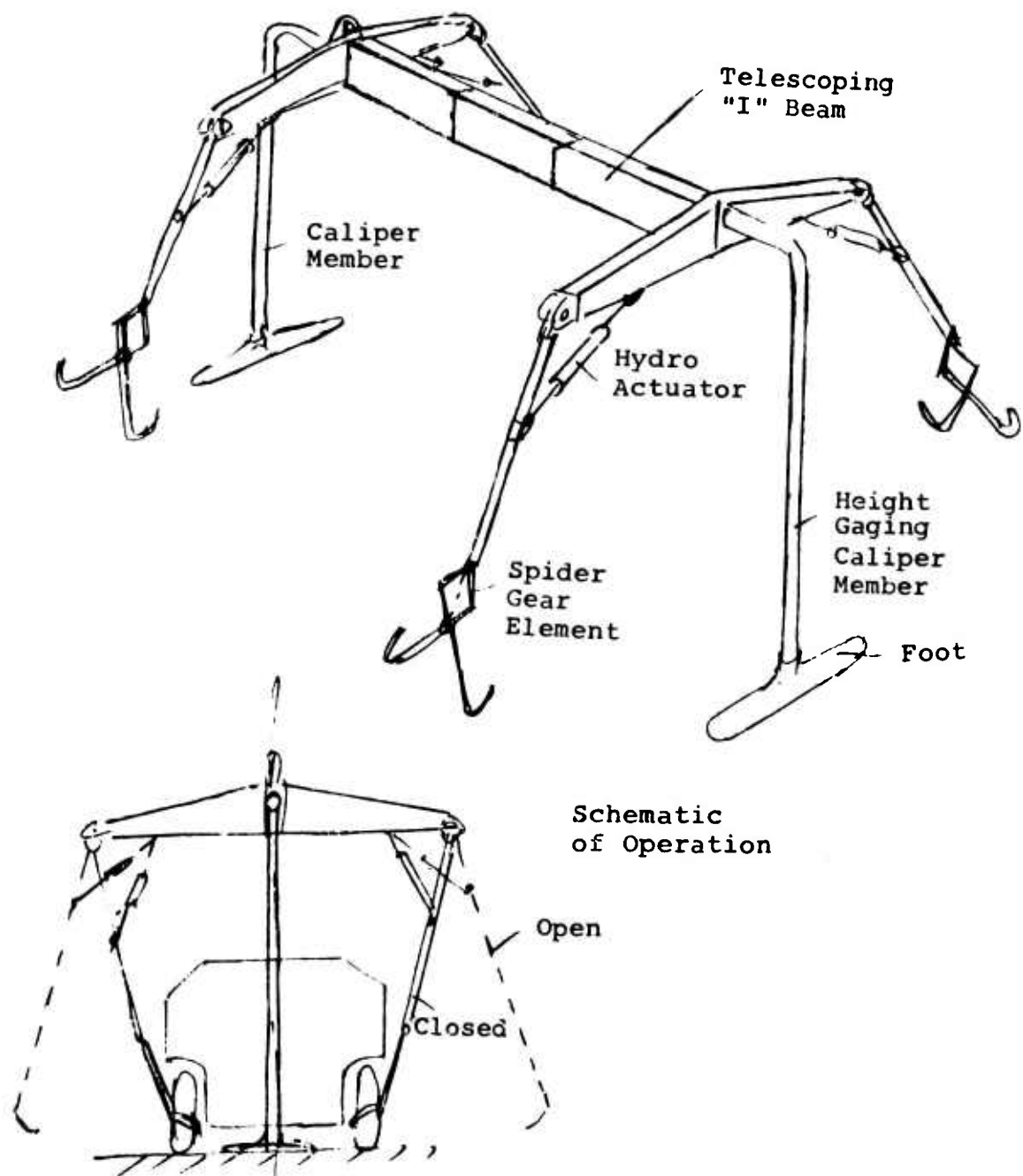


Figure 10. HALAS Automated Spider Gear/Frame System Concept for Handling Trucks and Wheeled Vehicles.

into the lifting eyes as long as the load could be acquired and lifted.

Many load types, and in particular Army tanks and tracked vehicles, all have rectangular planform. The length and width of such vehicle types does not vary appreciably for certain weight range. Two different sizes of frames could cover all such load types for medium and heavy lift helicopters.

The current prescribed method of loading and unloading such vehicles is by lifting eyes, which are visible and accessible from the top of some (such as tanks, self-propelled guns, personnel carriers) and hidden from top view on many others (such as trucks and service vehicles).

In the telescoping frame concept, the lifting eyes are disregarded. The frame, of rectangular shape, is lowered to the ground and appropriately frames the vehicle within. The telescoping action allows the frame to be expanded such that a clearance of some 2 feet all around is produced between the vehicle and the frame. This clearance permits the frame to be lowered over the vehicle without banging against the loads. The operation of load acquisition is fairly simple. Once on the ground, the telescoping action is activated by the helicopter operator to contract the frame around the tank tracks.

In this version, the frame is of the telescoping type; the track/wheel stopping wedges are adjustable to form a wedge angle just right for the local slant of the vehicle track. The frame would be equipped with short safety structure at the front, aft and side to secure the load. In operation of engagement, the frame is contracted around the tracks until the fences contact the tracks at the level of the driving sprocket wheels. Then the automatically adjustable wedges hinged at the tip corner of the wedge would be pushed up against the tracks and locked in position. The supporting forces would be distributed between the first driving wheel and the runner wheel. The wedges and the supporting structure can be designed to withstand the necessary loads.

The design features of the telescoping frame would include four lifting lines from the frame corners to the double spreader beam. The double spreader beam of "I" planform, with the longer beam along the fore-and-aft axis, contains the beam capable of telescoping adjustment to fit different size loads. Such adjustment, however, is not related to the actual engagement operation and could be done prior to the mission. The cross members of the "I" spreader beam must be broader than the contracted frame to avoid damage to the load by contact with the lines.

The telescoping action of the frame would be powered either electrically or hydraulically. The best approach will be determined in the design study, since the difference between the contracted and fully expanded frame size will have to be limited to only several feet of linear dimension (perhaps 4 feet for the cross members, 10 feet for the long members). It seems that two sizes of frames would be needed to fit the spectrum of different load sizes for light and heavy lift helicopter operation. Also, since the weight of the loads can be varied up to 23 tons, the frames may have to be built for several useful load ratings. Otherwise, it will be very inefficient and uneconomical operationally due to a very poor load-to-frame weight ratio when a frame capable of lifting 23 tons is used for lifting a lightweight load of about the weight of the frame.

The configurations and characteristics of all the major Army tanks and tracked vehicles that could be airlifted by medium and heavy lift helicopters have been analyzed. The basic data useful for configuring the telescoping frame load acquisition system for handling the major Army tanks and tracked vehicles are summarized in Table 1.

For configuring the telescoping frame load acquisition system for handling tanks and tracked vehicle type loads, the maximum and minimum length, width, and front and rear track-to-ground clearance angle that cover the major types of Army tanks and tracked vehicles that could be airlifted by medium and heavy lift helicopters are as follows:

Length (In.)		Width (In.)		Front (Deg)		Rear (Deg)	
Min	Max	Min	Max	Min	Max	Min	Max
191	265	106	128	20	33	13.5	43

It is estimated that an adjustable frame with maximum length of approximately 26 feet, width of about 13 feet, and wedged track support adjustable to a maximum of 45 degrees is sufficient to handle all the major Army tanks and tracked vehicle loads. The adjustable wedged track support could be designed with two to three segments to form the necessary slope needed to support the vehicles. This provision does not seem necessary for supporting the tanks and tracked vehicles. It seems highly desirable to incorporate this design feature for handling Army trucks and wheeled vehicles using the telescoping frame HALAS concept.

TABLE 1. CONFIGURATION DATA FOR ARMY TANKS & TRACKED VEHICLES						
Load Type	Length (In.)	Width (In.)	Height (In.)	Front Track-To-Ground Clearance Angle (Deg)	Rear Track-To-Ground Clearance Angle (Deg)	
M551 Armored Recon Airborne Assault Vehicle	248	110	100	33	30	
M113 Armored Tracked Personnel Carrier	191	106	100	22.5	13.5	
M108 Self-Propelled Howitzer	240	128	114	20	22	
M110 Tracked Self- Propelled Howitzer	264	124	108	30	43	
M548 Tracked Cargo Carrier	232	106	100	22	13.5	
M106 Self-Propelled Mortar Carrier	194	112	98	22.5	13.5	
M125 Tracked Mortar Carrier	191	106	100	22.5	13.5	
M107 Self-Propelled Field Artillery Gun	265	124	108	30	43	

## Application of Telescoping Frame HALAS Concept for Handling Army Trucks and Wheeled Vehicles

The procedure for this application will be to lower the frame to the ground around the load to be lifted, and then to lift the frame until a contact is made with the underside of the vehicle chassis structure, just aft of the front bumper and just forward of the rear bumper. In this manner, the vehicle would be lifted directly by its structural members. The supporting forces would be at a higher level, close to the c.g. level, improving overall load stability. Bypassing the wheels and their elastic connection to the body eliminates some troublesome degrees of freedom of motion in the dynamic flight environment.

However, inspection of Army trucks and wheeled vehicles has shown that only two major vehicle types, identified as 2½-ton 6x6 M35 and 5-ton 6x6 M55 trucks, could possibly be lifted by this method without incidental damage to other non-structural appendages. Although these two types of Army trucks are popular in quantity, the application of this HALAS concept to Army trucks and wheeled vehicles is limited.

This application seems more flexible when considering another mode of engagement using this HALAS concept for handling Army trucks and wheeled vehicles by providing the frame with wheel locking wedges, front and aft, effectively lifting the vehicles by their wheels. The wedges would be a part of the frame structure and be capable of supporting the truck when subjected to the expected dynamic load factors in flight transfer. As an additional safety provision, in the event of large dynamic swinging motions in flight, adjustable fences are provided, front and aft, which are hinged at the frame. The fences are made to contact the wheels at the axles' level and be locked in this position. The truck would be contained on the sides automatically by contracting the sides of the frame against the wheels. Some padding of the side members would prevent scratching of the load.

An additional retractable wedge, which could fit between the rear two pairs of wheels (on the three-axled vehicles), was considered for giving a more secure containment when in flight and for providing better loading distribution. The front and rear stopping and supporting wheel wedges would impose horizontal load components on the vehicle axles. Such loads may be considerable under certain flight conditions. It is not known at present what the allowable loads are for the Army trucks and wheeled vehicles.



## Analysis of Telescoping Frame HALAS Concept

Typical Army tanks which were selected for this analysis are M106, M113, M125, M548, M551, and M108. The wheel base, vehicle length, track-to-ground clearance angle and the height and size envelope are analyzed.

A clearance of 2 feet on all sides of the tank is assumed to be a minimum clearance required in placing the telescoping beam around the tank for airlifting operation. The basic telescoping frame HALAS design consists of a base frame made of an "I" beam. The base frame rests on the ground after being lowered around the load. The extendable frame has an extension length of 11.5 feet. Either two or four hydraulic cylinders will be needed to provide the telescoping capability. The typical hydraulic cylinder that could be utilized for this design has the following characteristics:

Bore 2 in.

Rod Diameter 1-3/8 in.

Thread Style-Intermediate Male

Cylinder Length 75-13/16 in.

Cylinder Stroke 69 in.

Cylinder Weight 82.6 lb

The maximum outside dimension of the telescoping frame is about 30 feet by 12 feet, which will allow a 2-foot clearance on all sides of the tank. The longitudinal sides of the frame could be adjusted to fit the particular wheel base and track-to-ground clearance of the group of Army tanks considered for this analysis. The approximate weight of the telescoping frame design is about 2500 pounds structure weight plus 330 pounds hydraulic cylinder weight, or a total of about 2830 pounds. It is capable of lifting all the major typical Army tanks up to 40,000 pounds, such as the M108 tank.

The advantage of the telescoping frame HALAS concept is that it is fully automatic, and no preparation of the load is necessary for automatic acquisition. The disadvantage of this system concept is that not all the Army tracked vehicles can be airlifted by this automatic load acquisition device.

#### 5.4 LIFTING LOOP HALAS CONCEPT

One candidate for a universal type of HALAS will be described in the following. If the basic type of the helicopter-based engagement device is a hook, the proper gear on the load should be some type of large loop permitting an engagement within a limited volume of relative position errors.

The lifting loop concept is illustrated in Figures 11 and 12. The load is provided with two triangle-shaped loops at the short ends. The helicopter-based hookup device has two arms at the ends of a load beam. The device is lowered to the proximity of the loops. Forward motion of the acquisition arms and liftup will result in engagement of the loops by the hooks for the initial position of the hooks anywhere within the triangular space of the loops.

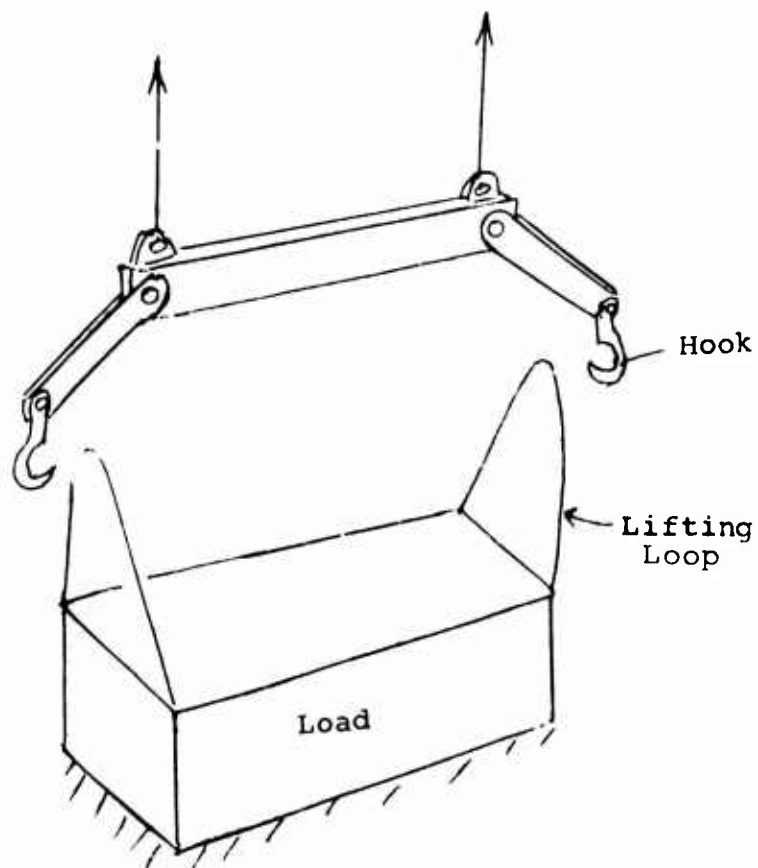


Figure 11. Lifting Loop HALAS Concept.

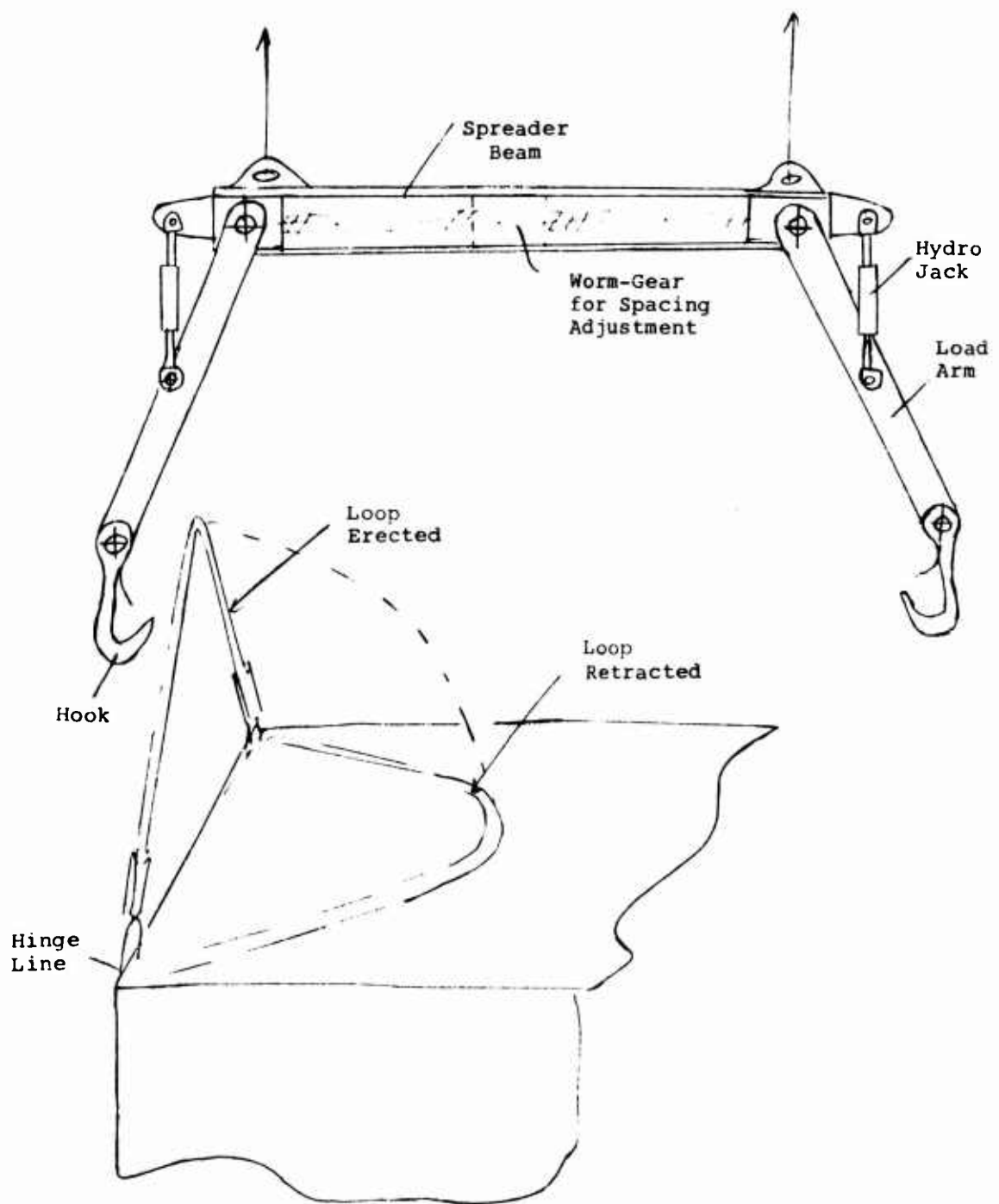


Figure 12. Lifting Loop and Hook Engagement Detail.

It appears that the concept could be applied to a broad spectrum of load types. However, standardization of the equipment may not be possible due to the dimensional variety and locations of the existing lifting provisions.

Adaptations of the lifting loop concept to acquisition of tanks, trucks, and aircraft are described in the following.

#### Tanks and Trucks

Standard provisions for lifting of tanks and trucks are pad-eyes or lifting eyes. Most tracked vehicles have four pad-eyes on the upper side. Such vehicles could be prepared for automatic lift-off by attachment of the lifting handle-type gear as shown in Figure 13. The lugs of the padeye should not be subjected to berding by the hoisting loads. A cross beam is provided, therefore, to take the compression loads.

Such lifting handle-gear could become a part of the tracked vehicle. When not in use, the loop would be laid down and out of the way. For a lifting operation, the loop would be raised to the vertical position; spring washers or friction washers would be tightened to prevent the loop from falling down to the retracted position.

The trucks usually have lifting eyes on the front and back. One adaptation of the lifting loop concept to the lifting eyes is shown in Figure 14. The engagement ends could be of the hook type, hooking up directly on the lifting eyes. Additional brackets will have to be provided for holding the lifting loop up. The trucks present a problem of their own if the rear lifting eyes cannot be used for lifting the vehicle. Special lugs are usually provided on three-axled vehicles. The lugs are on the chassis frame between the rear axles. In such cases the lifting loop concept could also be utilized by adding an attachment to the lifting lugs.

#### Aircraft

The lifting handle-and-hook concept for lifting aircraft would be used as follows. All Army aircraft require some kind of preparation. The result of such preparation is some form of lifting loop. Studies made by Sikorsky<sup>1</sup> for assessment of preparation gear and its placement on the load have shown that unique lifting provisions need to be attached to each type of Army aircraft. Sikorsky's investigations were aimed at a manual load acquisition procedure; thus the lifting provisions were of flexible rope or strap-type which had to be lifted to the hookup position by a crew member. Nevertheless, the general approach to the configuration and placement of the

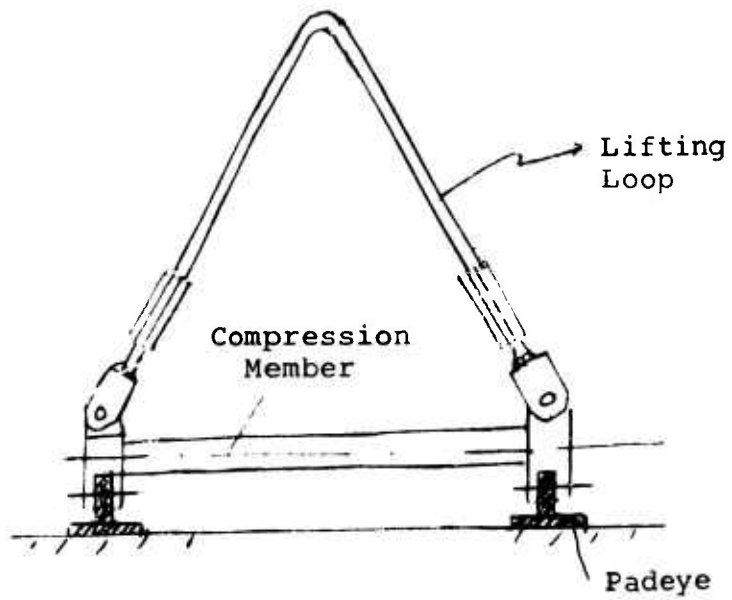
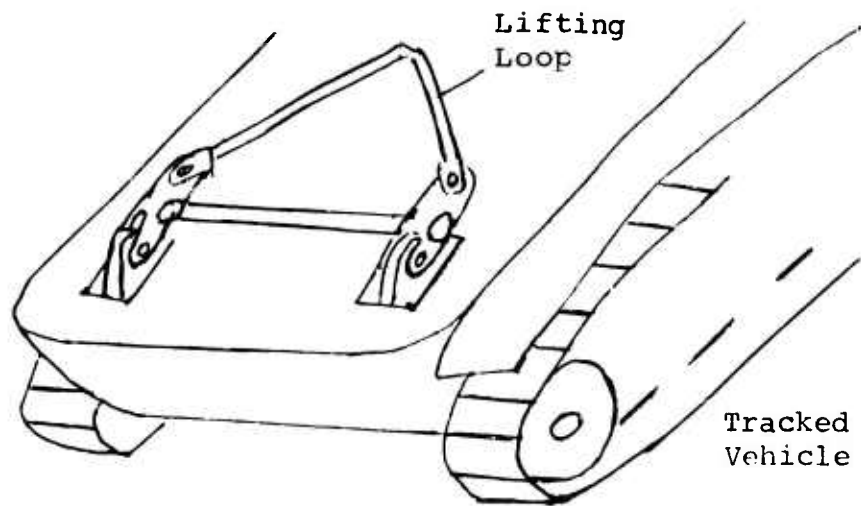
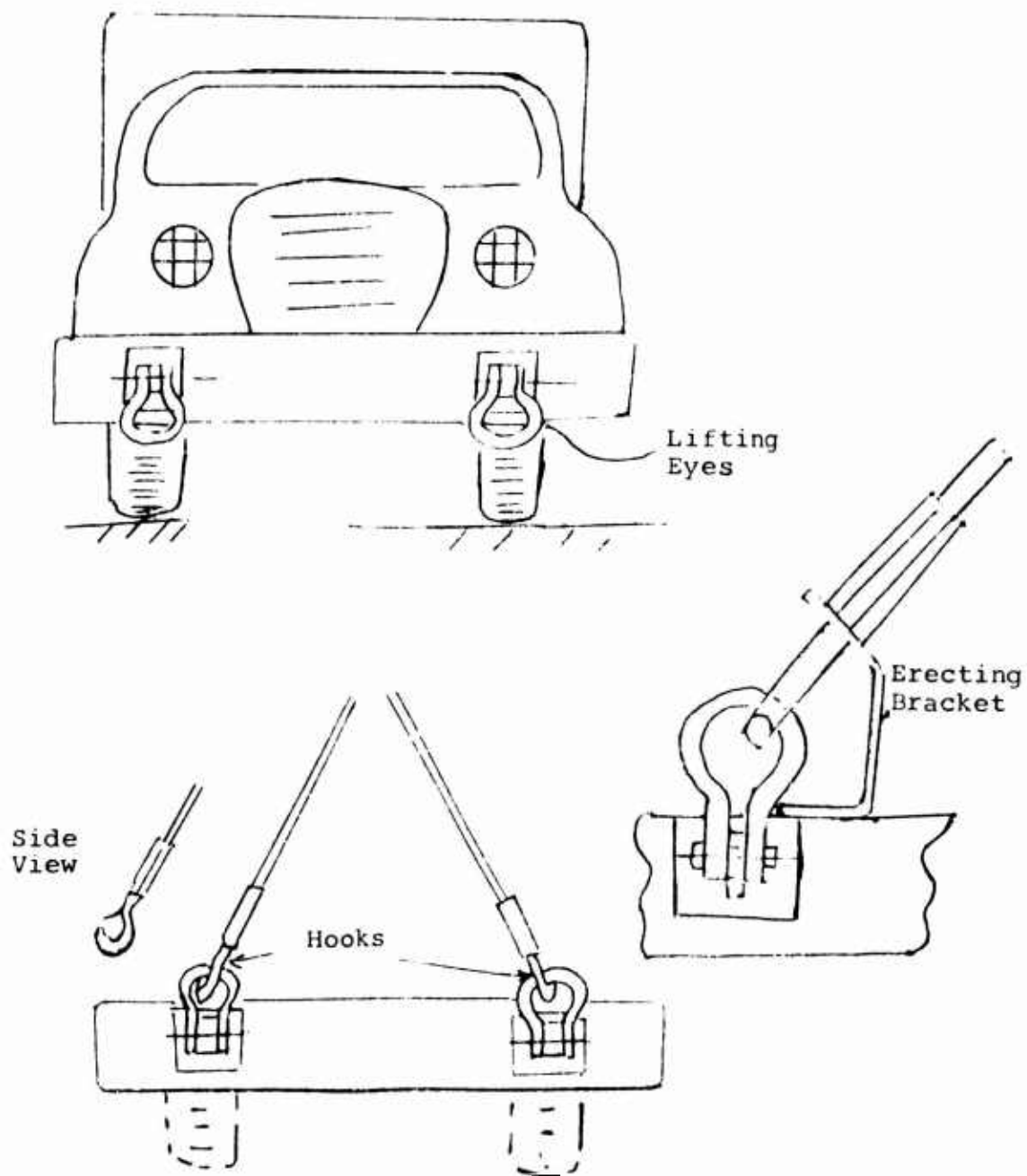


Figure 13. Lifting Loop for Tracked Vehicles.



Lifting Loop Adapter  
for Trucks

Figure 14. Lifting Loop for Trucks.

lifting provisions is considered here as valid; the flexible lifting provisions, however, will be replaced with rigid loops capable of standing erect for the automatic acquisition. One typical example of this is illustrated in Figure 15. Here the Army aircraft is prepared for liftup by the fuselage. The load preparation in this case consists of enclosing the fuselage contour at two fuselage bulkhead locations with wide saddle-type nylon straps. Triangular brackets are attached to the strap, and the handle frame is belted to the brackets as shown in Figure 16. Several sizes of straps and loops would be required to service all Army aircraft types. Attention must be paid to the placement of the brackets and to the angles that the loops form with the bulkhead contour to prevent the load from being crushed.

Another example of the strap-and-loop technique is shown in Figure 16, where this technique is applied to a heavy helicopter fuselage. In the above examples, the lifting provisions of the transporting helicopter were assumed to consist of two lines coming down to some form of spreader beam. In the case of only one line, the lift-up procedure can be modified by either converting one line to two-point pickup with a spreader beam or using a long enough loop so that the apexes can be taped to form a single loop for one-hook pickup.

The lifting loop concept is attractive since it is relatively simple to implement and, therefore, low in cost. It is suitable for both single-point and multi-point hookup, and it is applicable to most Army loads.

For practically all of the tanks and the tracked vehicles which are equipped with four upward-facing lifting padeyes, the lifting loop represents a simple mechanization of the automatic acquisition device. Two loops, one attached to the front set of padeyes and the other to the rear set of padeyes, make an arch longitudinally. The lifting loop could be bolted directly to the lifting padeyes on the tanks or other loads. The two lifting loops could be made to stand upward for a two-point hookup, or the two lifting loops could be placed together at the top to form a common arch enabling a single-point pickup. See Figure 17 for illustration.

These lifting loops for the tanks either could be a prefabricated lifting loop assembly or it could be assembled from a kit containing standard straight or curved members and the hookup loop for lifting engagement. If the length of the lifting loop is properly chosen and designed for the various loads, the compression member at the base of the lifting loop could probably be eliminated for most of the loads.

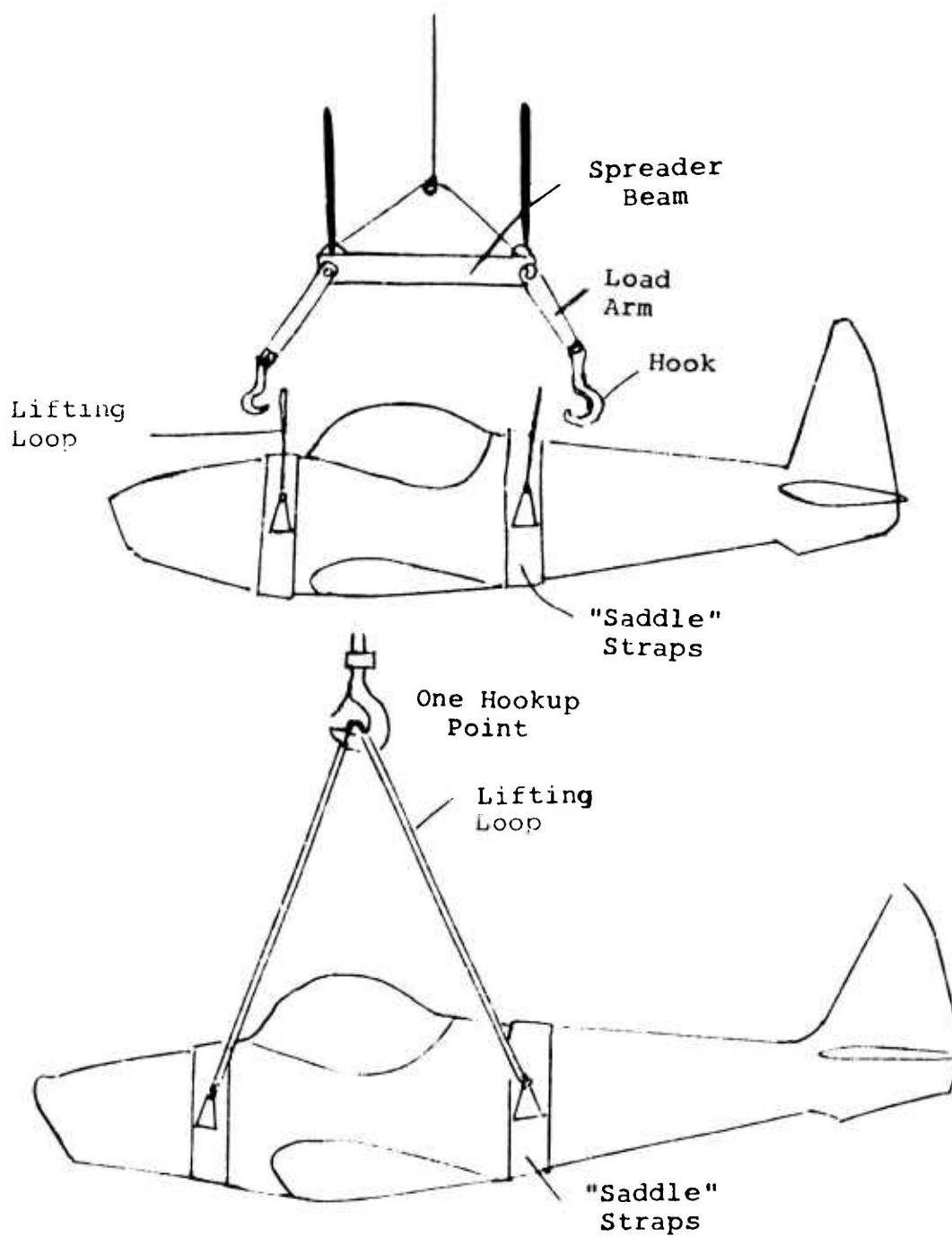


Figure 15. Lifting Loop Straps Concept.



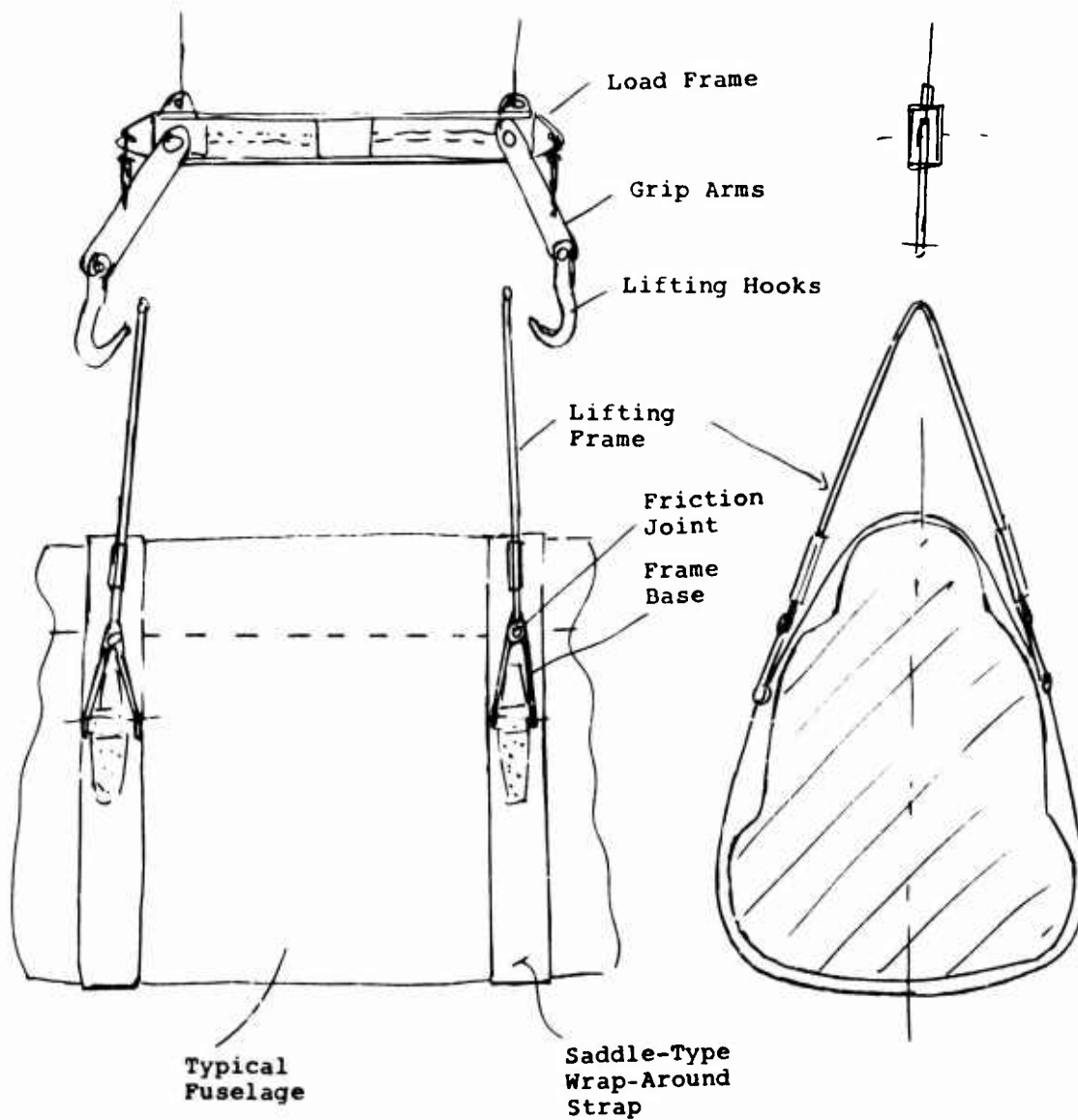


Figure 16. Acquisition of Army Aircraft and Helicopters - Lifting Frame on Straps Concept.

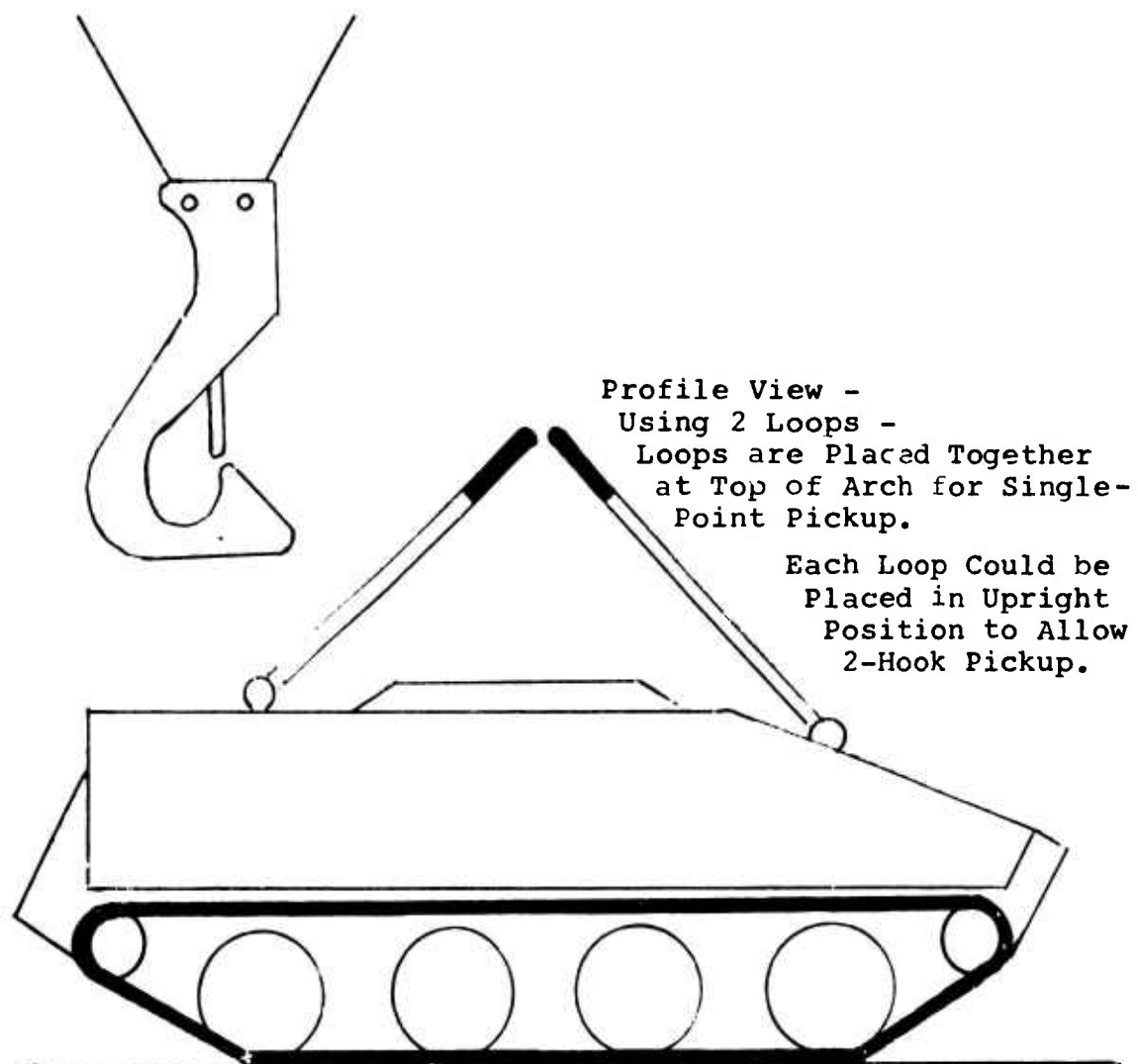


Figure 17. Typical Implementation of the Lifting Loop HALAS Concept for Handling Tanks and Tracked Vehicles.

The attachment of the lifting loop device for handling Army trucks is not as simple as the attachment on the tanks described above, due to the fact that on most of the trucks the aft lifting provision is hidden under the chassis of the truck and located between the two rear tandem wheels for most of the three-axled wheeled vehicles. The lifting loop system concept appears to be the most promising for handling this difficult load. One effective means of implementing this system concept as applied to the truck load is as follows. Attach the front lifting loop to the front set of the lifting padeye or rings on the front bumper of the truck. Attach short lifting adapter links to the side of the truck linking the lifting pins under the chassis, effectively bringing the hidden lifting pins outside of the vehicle chassis and to the side of the truck. No additional loads are imposed on the vehicle in doing this. This simple modification is desirable and highly effective for either manual or automatic load acquisition by helicopter. Based on this attached lifting adapter at the rear of the truck, the lifting loop could then be attached to this extended adapter on the side of the truck for two-point pickup by the lifting helicopter.

The lifting loop HALAS concept could be applied to a large variety of Army helicopter external loads. Wherever a designated lifting provision such as a lifting padeye, ring or pin is available, the lifting loop could be easily attached to the lifting provisions of the loads. The lifting loop could also be designed for attachment to the loads that do not have special lifting provisions, such as some of the howitzer gun barrels and supporting structures. The lifting loop and its attachment could be assembled with the use of a kit to fit most of the major load types of interest. Since most of the major loads would require some preparation for air transportation by helicopter, preparation to attach such simple lifting loops on the load should present no problems. The attractiveness of the lifting loop HALAS concept from an operational standpoint is that the engagement could be achieved by placing the lifting hooks in the triangular or semicircular space under the lifting loop and guiding by the lifting loop to the hookup point. Thus, large initial position errors of the hook in both vertical and horizontal sideways positions could be tolerated to achieve hookup. The acquisition engagement time will be shortened considerably when the proper hookup operational approach is established and followed.

The versatility of the lifting loop HALAS system concept is illustrated in Figure 18. The concept could be effectively implemented for handling such major Army loads as tanks, tracked vehicles, wheeled vehicles, pallets, gondolas, conex containers, shelters, and howitzers, as well as aircraft.

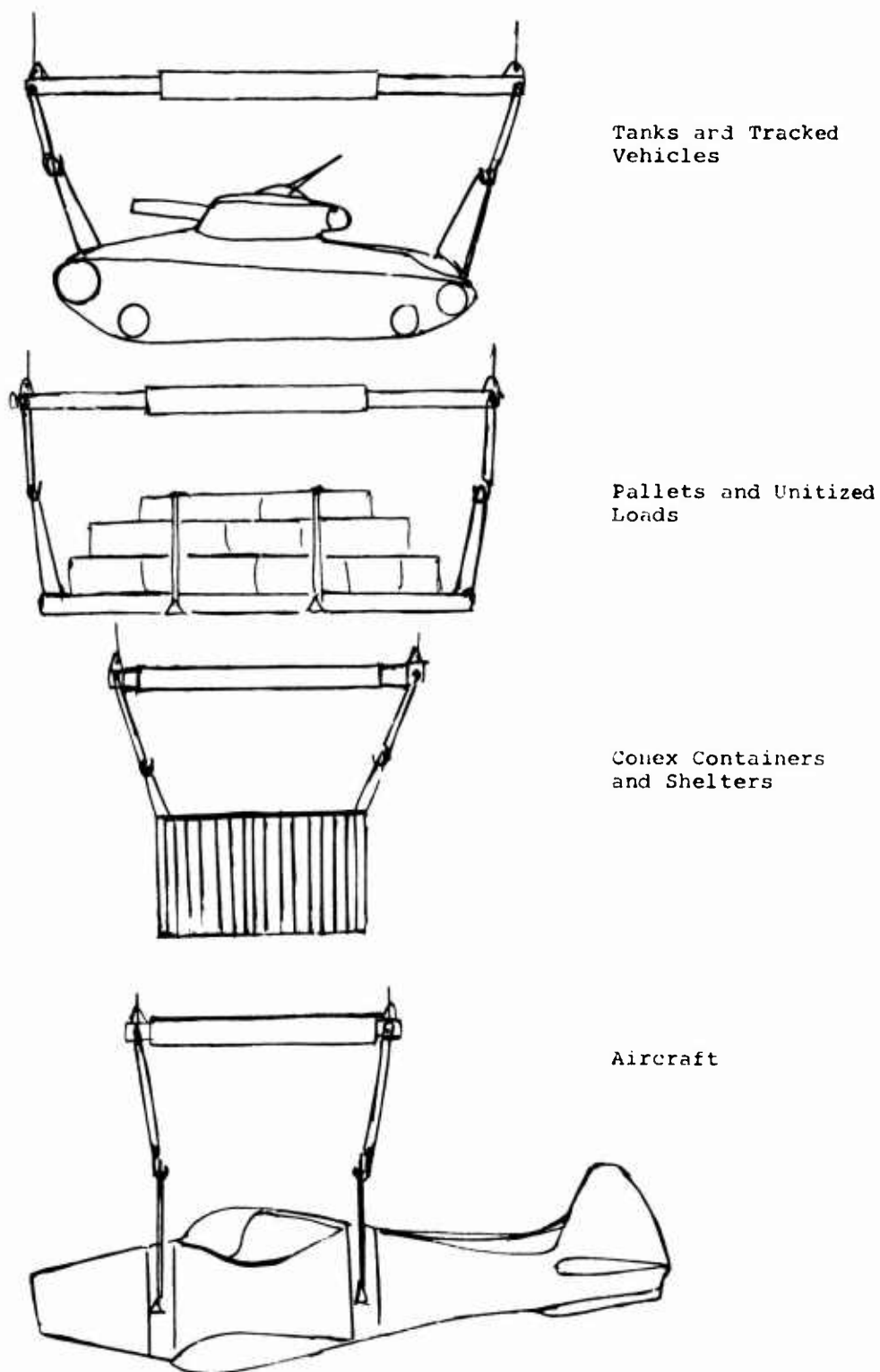


Figure 18. Versatility of Lifting Loop HALAS Concept.

Conex containers or shelters have lifting provisions at the top four corners. The lifting loop with end lugs could be easily attached to the four corners and erected vertically for lifting pickup. Attachment of the lifting loops to the gondolas could also be made in a similar manner to the top of the gondola for automatic lift-up by single- or two-point hookup. Pallets for handling unitized loads in the future could also be handled by the lifting loop attachment. Loops will be attached to clear the cargo and to provide sufficient room for hookup by the lifting hook automatically. Such lifting loops could be made retractable on certain load types and be permanently attached to some of the loads for effective acquisition operation. Aircraft and helicopters could also be handled by the lifting loop HALAS system. Special belt straps with the lifting loops attached could be strapped around the fuselage of the aircraft at the appropriate locations, such as the bulkheads forward and aft of the wing for automatic load lift-up operation. The size and configuration of the lifting loop could be designed to suit various types of helicopter and aircraft configurations for proper attachment and acquisition engagement. Since most of the helicopters and aircraft have to be pre-prepared for air transportation by helicopter anyway, the utilization of such a lifting loop HALAS system could standardize and greatly improve the efficiency of the hookup preparation and equipment in providing capabilities for automatic load acquisition by helicopter.

#### 5.4.1 IMPLEMENTATION OF THE LIFTING LOOP HALAS SYSTEM CONCEPT

The implementation of the typical lifting loop and hook HALAS concept using a tandem sling spreader beam is shown in Figure 19. The conceptual design of an erectable cargo lifting loop is shown in Figure 20. The lifting loop is basically made of steel cable imbedded in fiberglass sleeves which will provide the erecting rigidity for vertical hookup. The center top portion of the lifting loop is specially designed for hookup engagement with the lifting sling hook. Various attachments at the two ends of the lifting loop could be designed to fit the lifting padeye or links of various load configurations. For providing more room for maneuvering of the lifting hook, effectively allowing more height and position error of the lifting hook during the hookup engagement process, the lifting loop could be designed with a curved section to form a wider arch as shown in Figure 21, as compared to the triangular configuration formed by two straight legs of the lifting loop. In this curved lifting loop design, the bottom leg of the lifting loop is curved and joined by a tubular steel straight section to guide the lifting sling hook to the middle top hookup loop for proper hookup. The curved lifting loop will be straightened out under tight tension load during lift-up and will return to curved arch while under a no-load

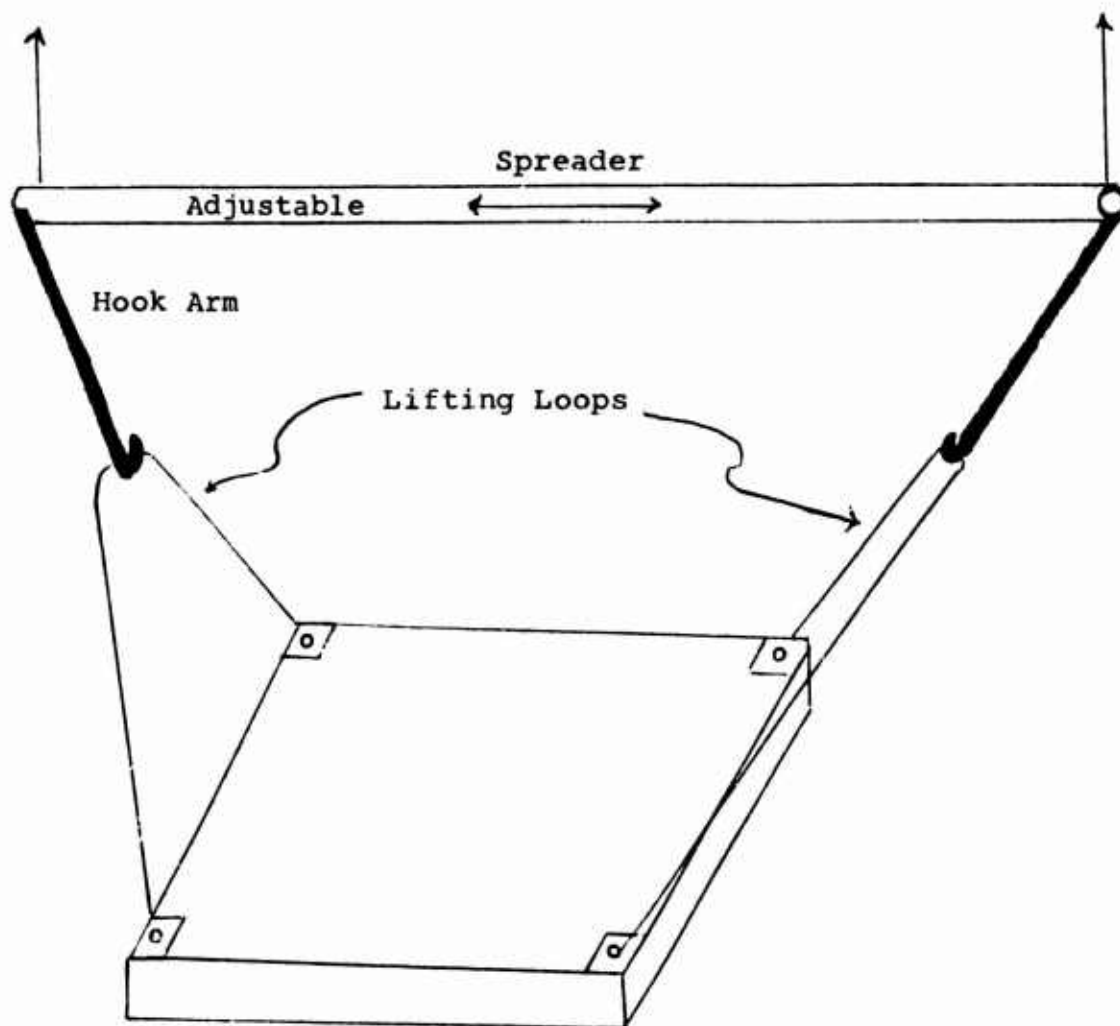


Figure 19. Implementation of the Lifting Loop HALAS System Concept.

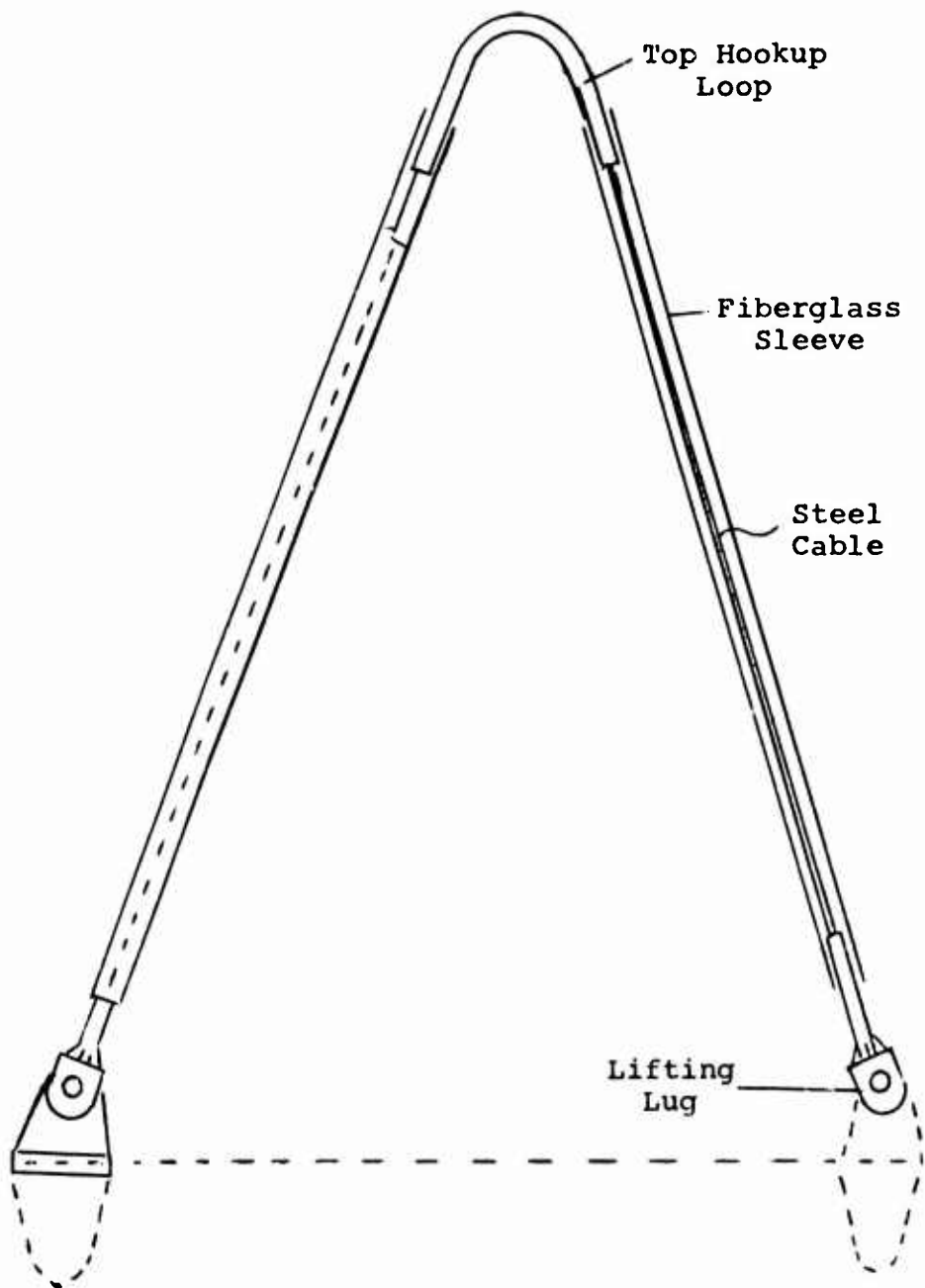


Figure 20. Conceptual Design of an Erectable Cargo Lifting Loop.

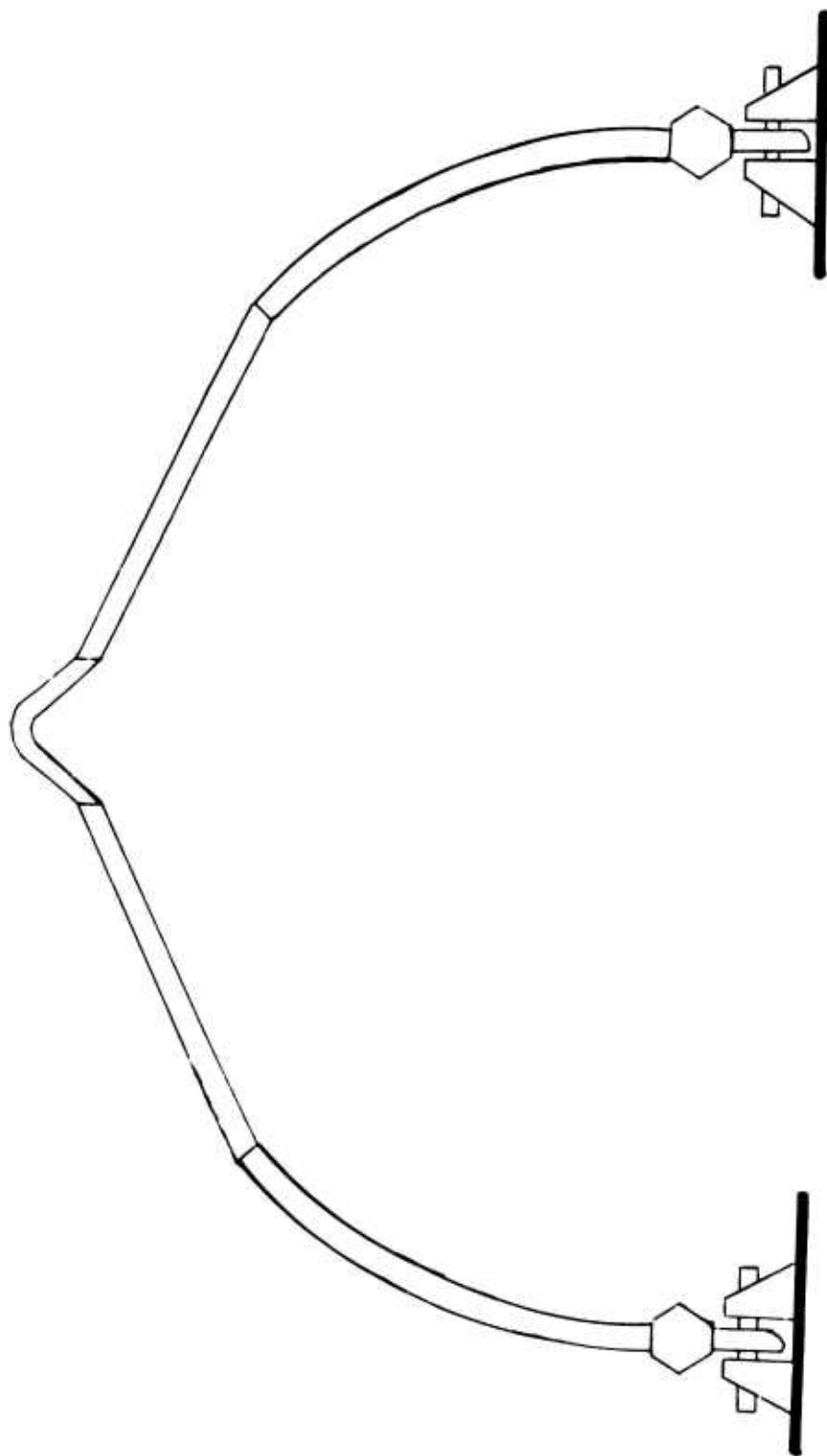


Figure 21. Curved Arch Lifting Loop Design.



condition. The widest opening of the lifting loop will be determined by the lateral separation of the lifting padeye of the load. The height of the lifting loop is adjustable, depending on the load configurations and lifting requirements. The height of the lifting loop could be adjusted by attaching a standard extension section to the legs of the lifting loop. With various designs of the attachment, the lifting loop could be attached to many different load types for airlifting by helicopter, requiring only minimal preparation.

The acquisition device to be carried by the helicopter consists of a spreader beam, either adjustable or fixed, with two articulated arms with lifting hooks. The hook arms could be activated remotely to swing in or out in a manner similar to hands reaching down to lift a basket by its handles. The typical design of the spreader beam with hook arms is shown in Figure 22.

The lifting loop design, especially the one shown in Figure 21, provides a considerable amount of space to allow for possible hook positioning errors in height and lateral excursion. A lifting sling hook placed within the loop of the lifting device could be guided to the proper hookup position, which is the top middle section of the lifting loop, without requiring strenuous effort for positioning and hookup. This design concept is perhaps one of the simplest that can be mechanized for handling a large variety of major Army loads. The design sketch shown in Figure 22 is approximately 1/20 scale of the actual size. The spreader beam design is chosen to be 20 feet long, which is sufficient to take care of most popular load types. The spreader beam with hook arms could be designed to have a telescoping feature to adjust the length of the spreader beam in order to handle a great variety of major loads. The length of the hook arms should be about 8 feet to permit proper adaptation of the hook spread to the lifting loops. It will provide sufficient margin for the position errors of the spreader beam relative to the lifting loop such that engagement could be achieved with little if any terminal positioning adjustment. The engagement concept using lifting loops and hook arms on the spreader beam appears promising due to its simplicity and versatility. The operational effectiveness requires some experimentation.

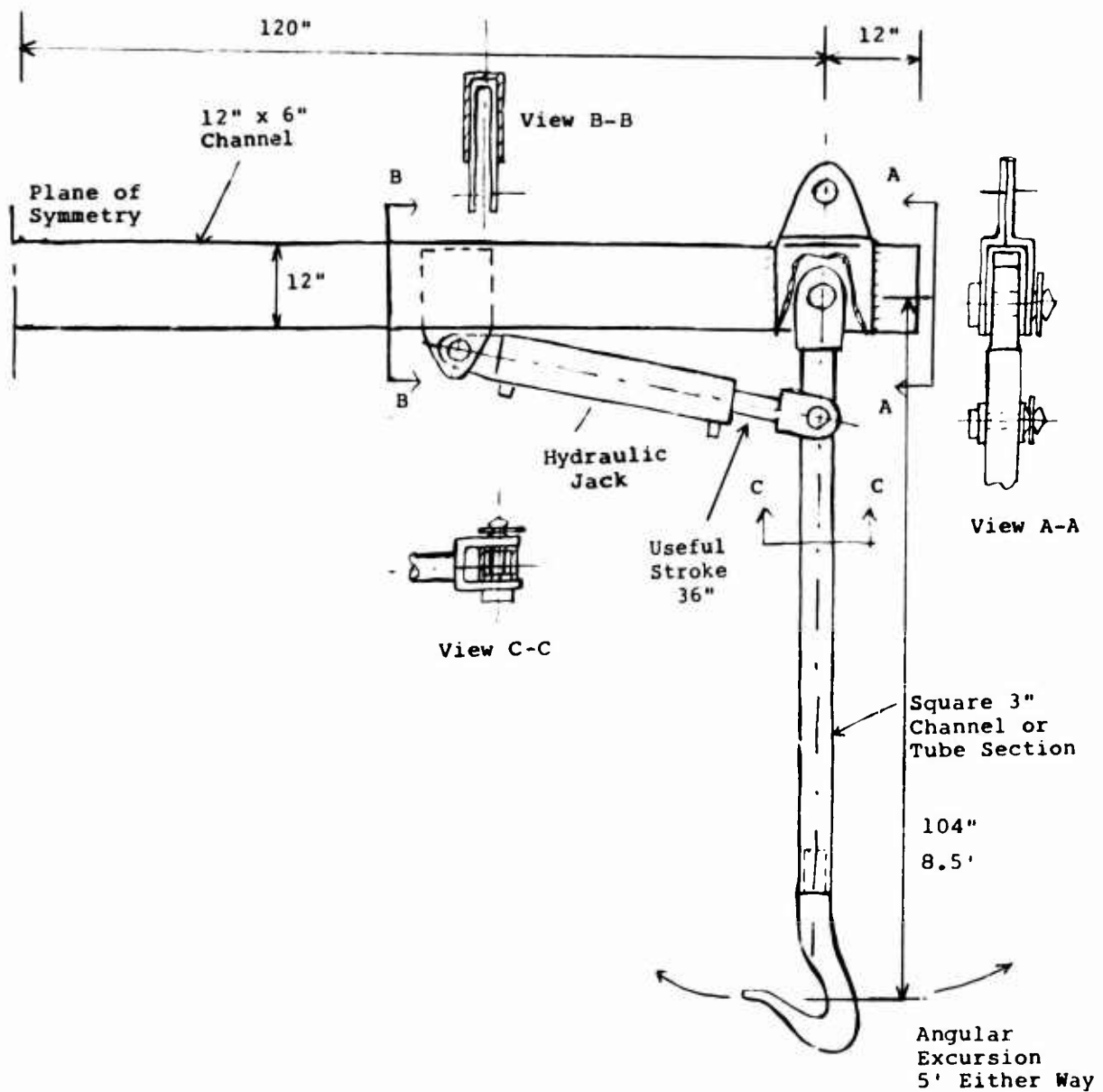


Figure 22. Typical Design of the Spreader Beam With Hook Arms for the Lifting Loop HALAS Concept.

#### 5.4.2 TONG-HOOK LOAD ACQUISITION DEVICE FOR LIFTING LOOP HALAS CONCEPT

In a static loading environment, as the load and the acquisition device are relatively stable with respect to each other, the engagement of the lifting loop by the twin-hook could be achieved without any difficulty. However, a more positive and effective engagement device is needed for the load acquisition operation in a dynamic environment to allow greater height and positioning error with respect to the lifting loop attached on the load.

The design of the tong-hook load acquisition device for the lifting loop HALAS concept is presented in Section 8.3.

For two-point sling hookup, two pairs of the tong-hooks will be equipped at the fore and aft ends of the spreader beam. Each tong-hook consists of two clamp arms that could be opened and closed either mechanically or by electrically driven motor and worm gear arrangement. A mechanical or electrical locking mechanism could be provided for positive locking after hookup. The opening and closing of the tong-hook mechanism by an electric-motor-driven worm gear design is illustrated in Figure 23.

After the proper positioning of the tong-hook load acquisition device over the lifting loop of the load, the tong-hooks could be swiftly closed. The lifting loops will then be enclosed in the tong-hook. The proper positioning of the tong-hook acquisition device with respect to the load does not require high-precision positioning and altitude hold capability of the helicopter. It is estimated that if the height of the helicopter or the load acquisition device could be controlled within an accuracy of 4 feet, and the longitudinal distance of the acquisition device with respect to the lifting loop of the load as well as the transverse or lateral position within 4 feet, the hookup engagement could be easily achieved. This height and positioning hold capability could be easily achieved by current cargo-carrying helicopters such as the CH-54 and CH-47. The short-term altitude hold capability of the above load-carrying helicopter is about 6 inches to 1 foot, and the short-term position hold capability is about 1 foot. The altitude hold and the position hold capabilities of the heavy lift helicopter are much better than the above stated figures for the current heavy load-carrying helicopters. Although the required specifications are in terms of a few inches, realistically, the heavy lift helicopter could possibly achieve the height and positioning accuracy of within about 1 foot. In view of these altitude and position holding capabilities of the current and future heavy lift helicopters, the proposed tong-hook load acquisition device

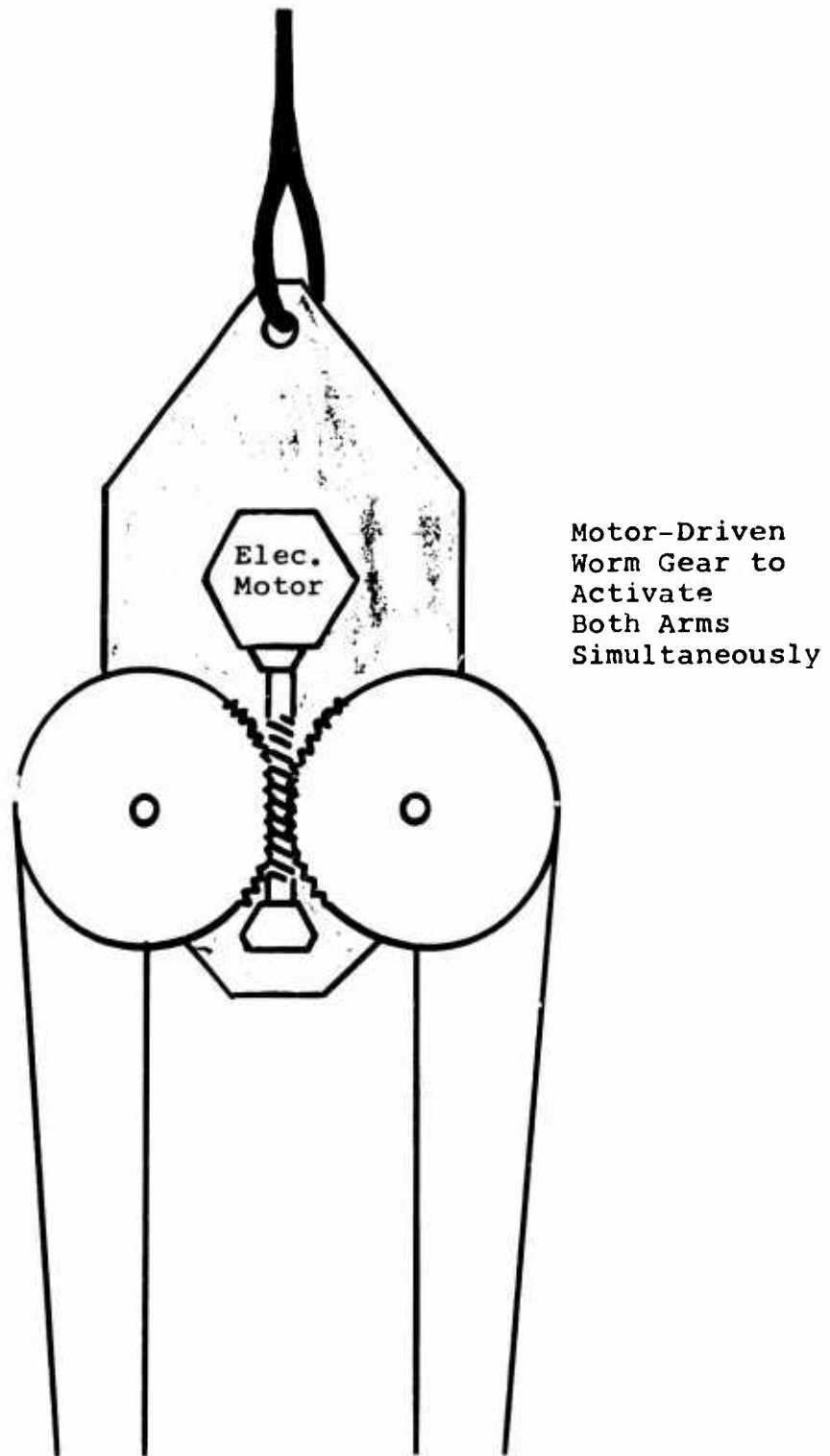


Figure 23. Electric-Motor-Driven Worm Gear Mechanism for Tong-Hook Acquisition Device.

for the lifting loop HALAS system concept could perform hookup engagement without any difficulty. The proposed system is particularly suitable for a two-point sling load pickup, which is important for achieving in-flight load stability. The proposed tong-hook load acquisition device could be utilized for single-point sling hookup operation as well. In this case, the lifting loop design will be slightly different from the two-point sling hookup operation. Positive hookup could also be achieved by the proposed tong-hook load acquisition device within about a 4-foot cube in height, longitudinal, and lateral position accuracy.

Figure 24 illustrates one possible mode of hookup by the tong-hook load acquisition device into the lifting loop. While the tong-hook arms are closing, the lifting loop could be hooked up by one side of the tong-hook. An especially designed hook configuration as shown in Figure 24 enables the tong-hook to close and provides positive hookup.

It is predicted that the proposed tong-hook load acquisition device could achieve more positive and efficient hookup of the lifting loops than the plain twin-hook load acquisition device previously presented. The actual operational advantages of these design approaches could only be realized by testing. Through the use of the lifting loop attachments, all the Army loads could be automatically acquired for air transportation by helicopter utilizing the proposed automatic load acquisition approach. The lifting loop/tong-hook HALAS concept is a universal automatic helicopter load acquisition system applicable to all the Army loads prepared prior to hookup.

In consideration of flight safety, it is mandatory to incorporate some means for emergency release of the external load. For the automatic load acquisition system design presented in this section as well as various other conceptual system designs presented in this report, it appears quite impractical to incorporate an emergency load release mechanism at the hookup point of the automatic load acquisition device. The load release should be provided on the lifting sling supporting the automatic load acquisition equipment from the helicopter.

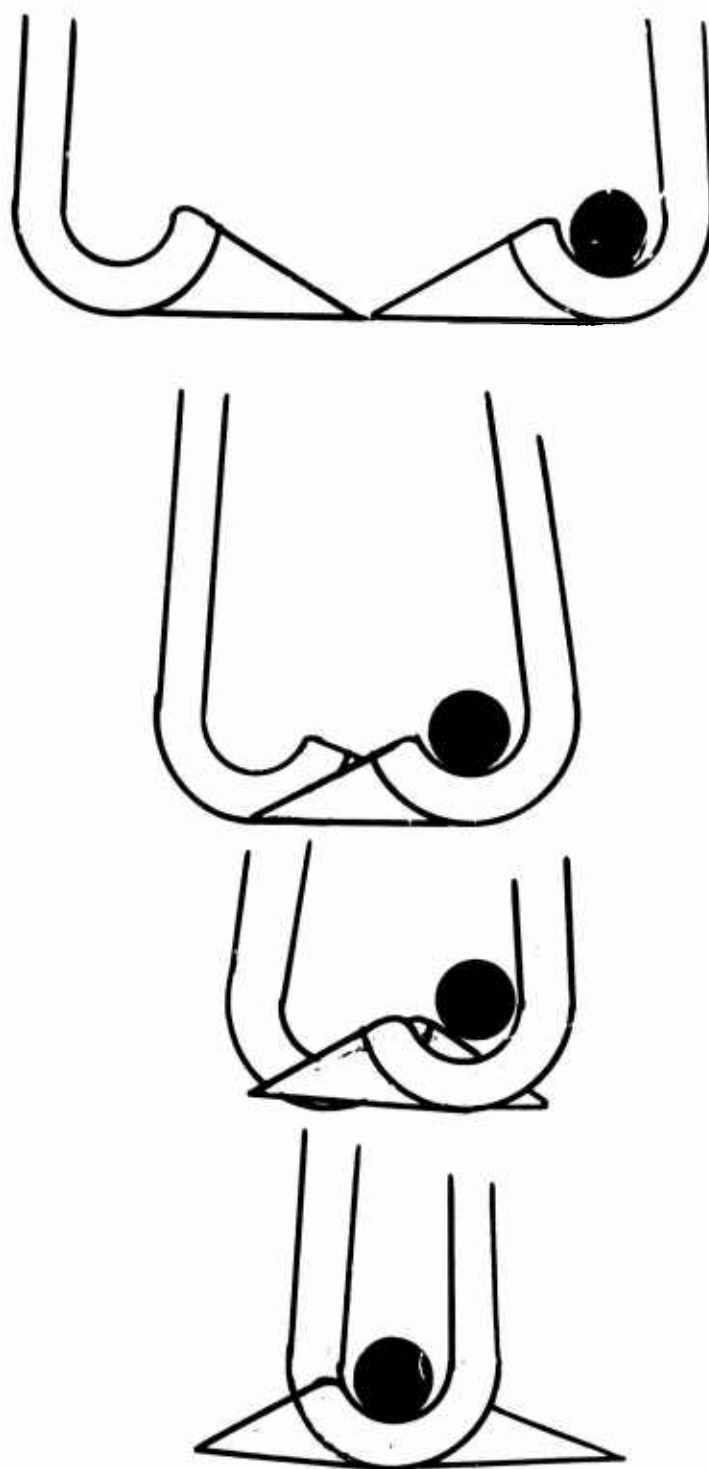


Figure 24. One Mode of Lifting Loop Hookup  
by Tong-Hook Acquisition Device.

#### 5.4.3 EXPLORATORY TESTING OF SMALL LIFTING LOOP AND HOOK SYSTEM MODELS

Simple small-scaled model testing was conducted to verify the lifting loop HALAS system concept and to investigate its operational problems. The small-scaled model of the lifting loop acquisition device, a spreader beam with hook arms, is shown in Figure 25. It is drawn in 1/20 scale of the actual dimension shown in Figure 22. The hook is attached to a tubular arm which is pivot mounted on the spreader beam. The motion of the arms is activated by small electric motors (3-volt slot car type of mini-electric motor) using a reduction gear consisting of a long threaded shaft and a swivelled nut attached to the arms of the hook. The complete test model setup consists of a simulated typical load with two lifting loops, the spreader beam with hooks, hoisting mechanism capable of winching the spreader beam acquisition device, and an electrically activated control box.

The length of the two lifting sling cables is 5 feet, corresponding to 100 feet in actual length. In this simulated operational test, the operator looks downward near the winching point of the simulated acquisition device. A viewing port is provided for the operator through an aperture in the baseboard on which the winch of the load is mounted. The relative position of the acquisition spreader beam and the simulated load with lifting loops is arranged to provide proper perspective for the operator. The up-and-down winch movements of the acquisition spreader beam and the hook arm activation will be governed by push-button switches on the control box. In the future, the hovering motion of the helicopter and the dynamics of the spreader beam acquisition device with the helicopter should be introduced in the test setup in order to explore the operational efficiency and special problem areas. The objectives of this crude, small-scaled model testing are threefold:

1. To verify the feasibility of the proposed concept in simulated load acquisition approach.
2. To investigate the operational problems in load acquisition and engagement of the hook and lifting loop.
3. To determine the requirements of the system operational testing in a more realistic environment.

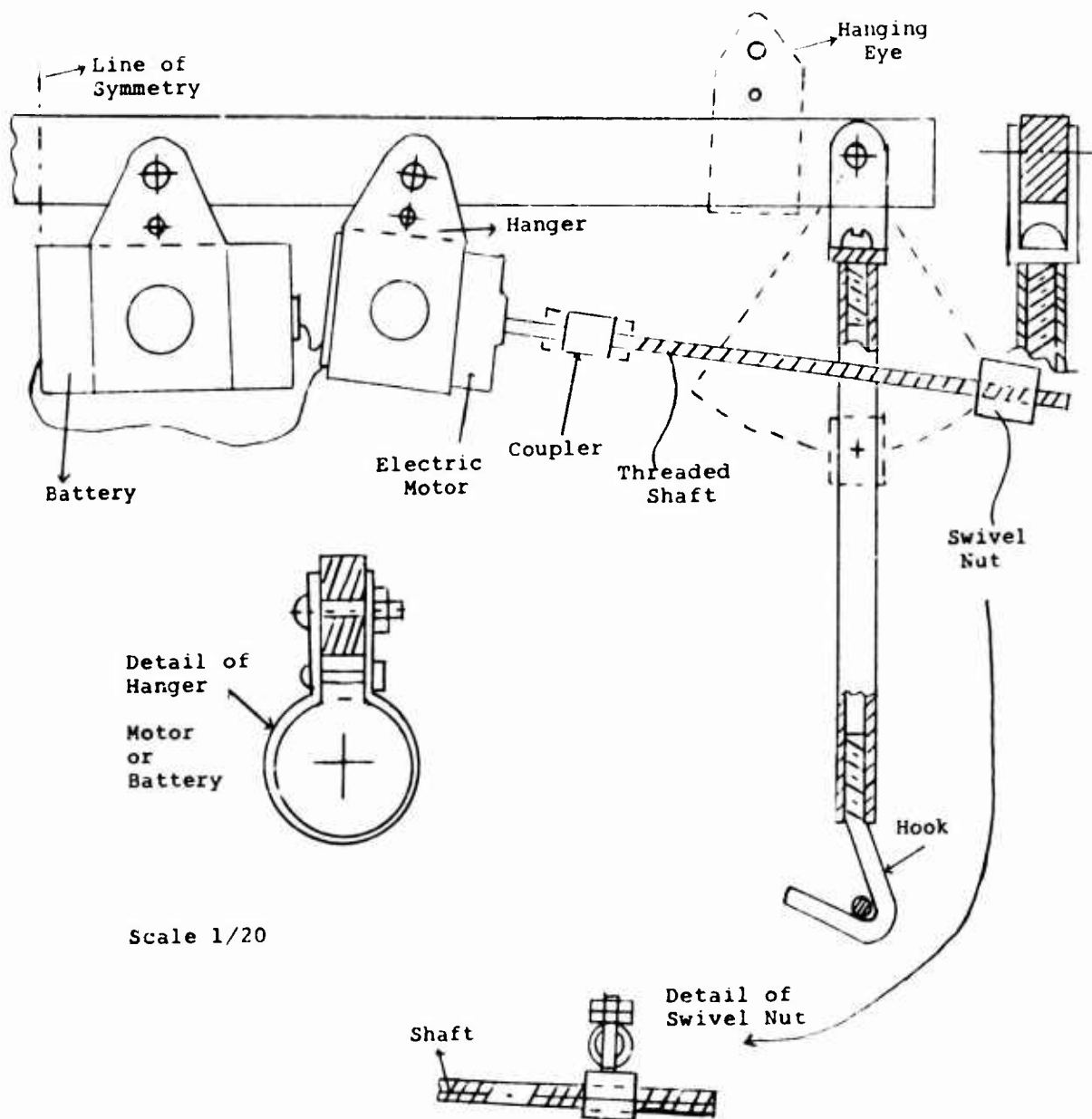


Figure 25. Small Test Model of Lifting Loop Acquisition Device.



#### 5.4.4 EXPLORATORY MODEL TESTING OF LIFTING LOOP HALAS CONCEPT

##### Exploratory Test Setup

A model of approximately 1/20 scale was assembled using mostly off-the-shelf parts; only the threaded shaft was specially machined. A facsimile of a conex container was equipped with a pair of lifting loops at the two ends. The acquisition device consisted of two arms with hooks at the ends of a spreader beam. Two lifting lines were attached to the brackets on the spreader beam. The hook arms were pivoted at two ends of the spreader beam. A screw jack arrangement activated by miniature electric motors allowed the hook arms to be opened or closed. A scaffolding consisting of two ladders about 5 feet tall was used to support two wooden beams. A separate short piece of wooden boarding was placed on the top of the beams to represent the base of the helicopter. Two pulleys were attached to the opposite edges of the board to represent winching mechanism for the lifting slings. A nylon fishline was lowered over the pulleys and attached to the lifting brackets of the spreader beam with hook arms. The line, when gripped by the hand of the operator, could be raised or lowered for positioning of the acquisition device. The power supply wires were attached to the electric motors and the other ends secured to the control box containing batteries and a two-way switch. An operator sitting on the beams of the scaffolding could look down at the load and at the acquisition device through the gap between the two beams. The exploratory test setup is illustrated in Figure 26. By using the 1/20-scale model and the separation height of 5 feet, this setup approximates the relative view of the load and the acquisition device that the load operator will see at about 100 feet altitude. Using the lifting line for control of the engagement and the control box for actuation of the arms, the operator could experience the problems of the acquisition process.

Two situations were simulated in this test:

1. Relative static position
2. Relative dynamic position

The relative static position would correspond to stationary load and condition of the helicopter position during load acquisition operation. The relative dynamic position would correspond more to the actual helicopter position while in station-keeping over the load in the environment of moderate gusts and turbulent conditions. The dynamic relative position was simulated for motions in the horizontal plane only. This

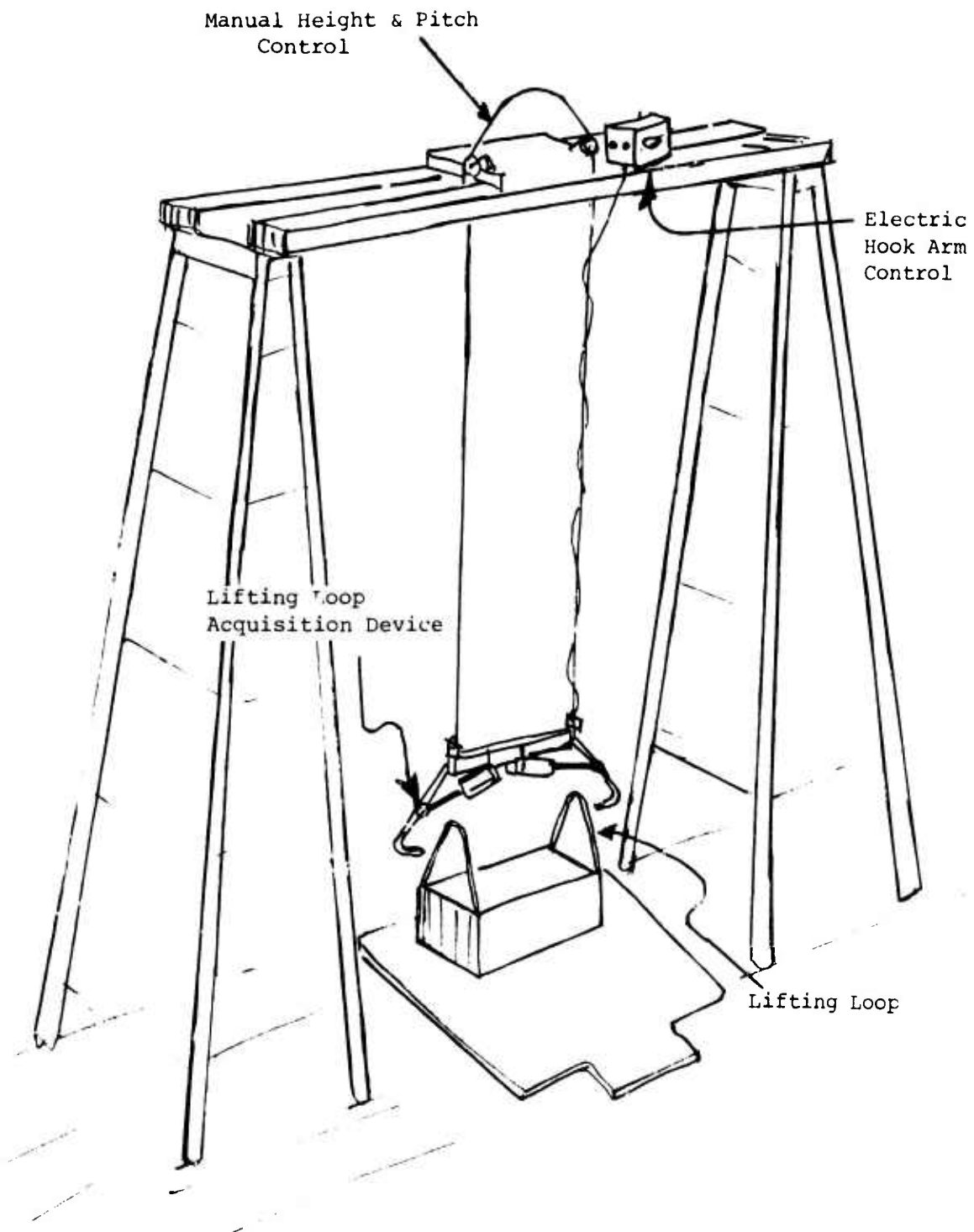


Figure 26. Exploratory Test Setup of Lifting Loop Load Acquisition Concept.

was accomplished by placing the load on a piece of wooden boarding and subjecting it to motions about some fixed reference. Since only the relative motions of the helicopter, the load acquisition device, and the load were of interest, such motion could be simulated by moving the load relative to the stationary helicopter base for creating the same effect. Major observations and results of the exploratory testing are summarized in the following section.

#### Major Observations and Results of the Exploratory Testing

Since the above described test setup is a simple pendulum, the frequency of the pendulum oscillation is a function of the pendulum length and therefore does not duplicate the frequency of oscillations in the real environment. The motions observed in the scaled model exploratory experiment were several times faster than those in the real operation. However, all the problems encountered with the scaled exploratory model would actually be present in the real situation except that the speed of the motion would be much slower.

#### Judgment of Height

It is sufficiently evident that the judgment of the height between the load acquisition hook and the lifting loop was fairly difficult. The separation height between the helicopter and the load in the test was simulated to be about 100 feet. The problem will be greatly reduced if the helicopter hovers at a much lower altitude during load acquisition. If the helicopter hovers at 250 feet during load acquisition, it will be extremely difficult to judge the relative distance between the acquisition device and the load. It is believed that this difficulty would exist for any type of load acquisition device. The performance and efficiency of other automatic load acquisition systems would also be dependent upon the altitude hold capability of the helicopter.

#### Spreader Beam Pitch Angle Determination

The judgment of the pitch attitude of the spreader beam with the hook arms was one of the problems observed in the test. Lowering of the load acquisition device while pitched to a position for engagement resulted in a misengagement of one hook or the other. An attempt at leveling off of the spreader beam resulted in overcorrection and in inducing the pendulum type oscillation of the acquisition device. Such oscillatory motion could easily be induced by pitching of the acquisition device. This is not believed to be a critical problem in a real-life situation since the pitching of the acquisition device could only be introduced by asymmetric winching of the sling cable or by pitching the helicopter itself.

### Asymmetric Load Acquisition Engagement

The asymmetric hookup engagement could be caused by misjudgment of the relative height between the hook and the loop, the pitch attitude of the acquisition device, and the relative motion between the acquisition device and the load. There may be some benefit if the asymmetric load hookup engagement could be used in the engagement operation in rough weather environment. The load engagement from a slow forward-flying helicopter will probably be faster and more positive in acquiring the load when the load acquisition device is purposely pitched upward. The pitch angle will have to be sufficient for the forward hook arm to miss the rear lifting loop and enable the rear hook arm to engage the rear lifting loop first. Once a contact was made, both hook arms would be activated inward, engaging the lifting loops. Such engagement maneuvers were tried during the test and proved to be quite successful.

### Lead Time for Engagement

The problems of load acquisition as featured above were intensified when simulating a dynamic environment. In stationary helicopter load engagement situations, there was no problem in placing the acquisition device over the load. The dynamic environment was simulated by inducing relative random motions to the load with respect to the load acquisition device. The load was moved randomly about some fixed mean reference position. It is observed that the positioning of the acquisition device over the load subjected to such random motion was quite difficult. However, after a short time of practicing, one gains proficiency and adopts a technique of "leading" the acquisition device to load engagement. The "leading" is done through a natural prediction of the acquisition device and the load's next relative position. This assumes, of course, that the relative position of the acquisition device of the load could be seen at all times by the load acquisition operator.

### Station-Keeping Requirements

The exploratory test indicated that the performance and efficiency of the load acquisition system are dependent on the station-keeping capabilities of the helicopter design. The data on station-keeping capability for the current load-carrying helicopters and the heavy lift helicopters are required in order to analyze and design the load acquisition system. The altitude hold, the pitch, roll, and yaw attitude hold, as well as the hover position hold accuracy of the cargo-carrying helicopters are needed to determine the range of movements required for the hook arms and their tolerable excursions.

## Remarks

The problems encountered in the exploratory testing of the lifting loop and hook HALAS concept do not appear to be critical. The visual perception of the relative height is perhaps the most serious problem. To remedy this, some type of mechanical feeler device or relative height determination based on the altimeter of the helicopter and cable length indicator could be mechanized to indicate the relative height between the acquisition device and the load for the load acquisition operator. The pitching of the load acquisition device could be solved by controlling the winching for both sling cables.

The exploratory testing of the lifting loop and hook HALAS concept indicated that the concept could be easily implemented and that it is effective in automatic load acquisition. Considering the much slower relative motion between the acquisition device and the load in the real-world environment as compared to the much faster oscillation encountered during the test, there should be no difficulty for the load operator to achieve the automatic load acquisition using this proposed HALAS concept.

## 5.5 FORCEPS LOAD ACQUISITION CONCEPT

A concept for automatic handling of tracked and possibly wheeled vehicles is the forceps system concept. The forceps load acquisition concept is presently tailored for handling tracked Army vehicles. In this system concept, the load acquisition device consists of two pairs of scissor type or forcep arms pivoted about a tubular spreader beam. Two or four lifting sling lines are assumed in this case and are attached to the extended ends of the forcep arms. The bottom ends of the forcep arms are joined by a swivellable wedge pad. The wedge angle of the wedge pad is made so that it will fit a range of track-to-ground clearance angles of various types of Army tanks. In load lifting, the wedged pad serves as a support for the load. The angular position of the wedge pad relative to the forcep arms has some freedom of rotation and is self-adjusting to a particular track angle. When not loaded, the wedge angle will be set at a proper value for fitting under the tracks without digging into the ground while engaging the load. The extended short ends of the forcep arms are joined by hydraulic actuator jacks. Viewed from the front or rear, the forcep load acquisition device looks like a pair of frames capable of swivelling at the upper horizontal spreader beam. The forceps HALAS concept is illustrated in Figure 27.

The load acquisition system operation is illustrated in Figure

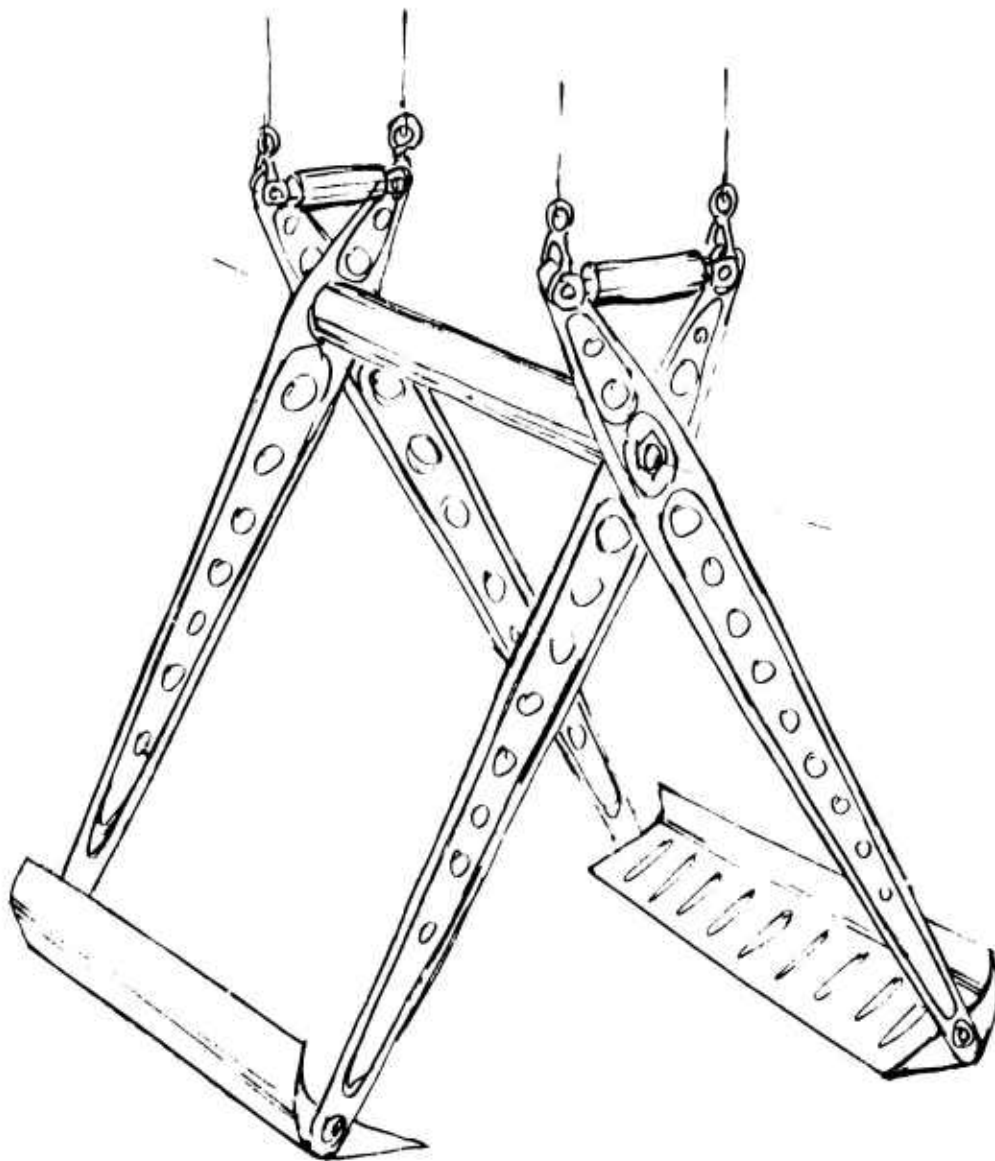


Figure 27. Forcep HALAS Design Concept.

28. Two or four lifting sling lines are attached to the upper hands of the forcep arms. The hydraulic jacks joining the upper forcep arms are fully contracted so that the lower long forcep arms are fully open. The large spacing between the front- and rear-wedged pads at the ends of the forcep arms permits positioning and engagement of tracked vehicles with considerable variation in vehicle length. The spacing is sufficient to allow several feet of clearance between the vehicle and the loading wedge. Once the forceps are lowered to position over the load, the hydraulic actuators are energized, moving the forcep arms down to engagement under the front and rear edges of the tracks. With the wedged loading pads firmly under the load, the hydraulic actuators are locked so the engagement is completed. This forcep concept reduces the complexity of the automatic load acquisition device to one cross spreader beam and two pairs of loading arms. The loading arms will be of "I" beam construction with the maximum depth at the main pivot, the depth corresponding to the maximum banding moment.

A rough estimate of the sizes involved is shown in the following: for a 20-ton payload, M108 Army tank, the forcep arms should be about 15 feet long, with 3 feet as the extended scissor arms on the other side of the pivot point. The maximum beam depth is about 12 inches, with "I" beam caps about 2 square inches in cross section areas using steel "I" beam construction. The estimated total weight of the whole load acquisition device is about 1200 pounds.

#### 5.6 LIFTING STUD/FORK-CLAW HALAS CONCEPT

The lifting stud and fork-claw HALAS concept is applicable to both the single- and two-point hookup sling system. This concept is particularly attractive for single-point hookup. Loads with lifting stud attachment could be hooked up and air-lifted very efficiently. The lifting stud is a protruding element on top of multilegged supporting rods. The rods supporting the lifting stud are made of essentially steel cables imbedded in fiberglass sleeves to provide erecting rigidity. The lifting stud unit could be assembled into a two-legged, three-legged or four-legged lifting device with basic elements supplied in a kit for various load type applications. Some type of folding arrangement with hinges at the stud base could also be designed similar to the tripod support for a camera mount. This will allow the lifting stud with supporting rods to be compacted for ease in storage, transportation and installation. The design of the lifting stud/fork-claw HALAS system concept is illustrated in Figure 29. As shown in Figure 29, the load acquisition device is a fork-claw design. The engagement approach is much like the operation of nail removal by a hammer claw. The open claw and

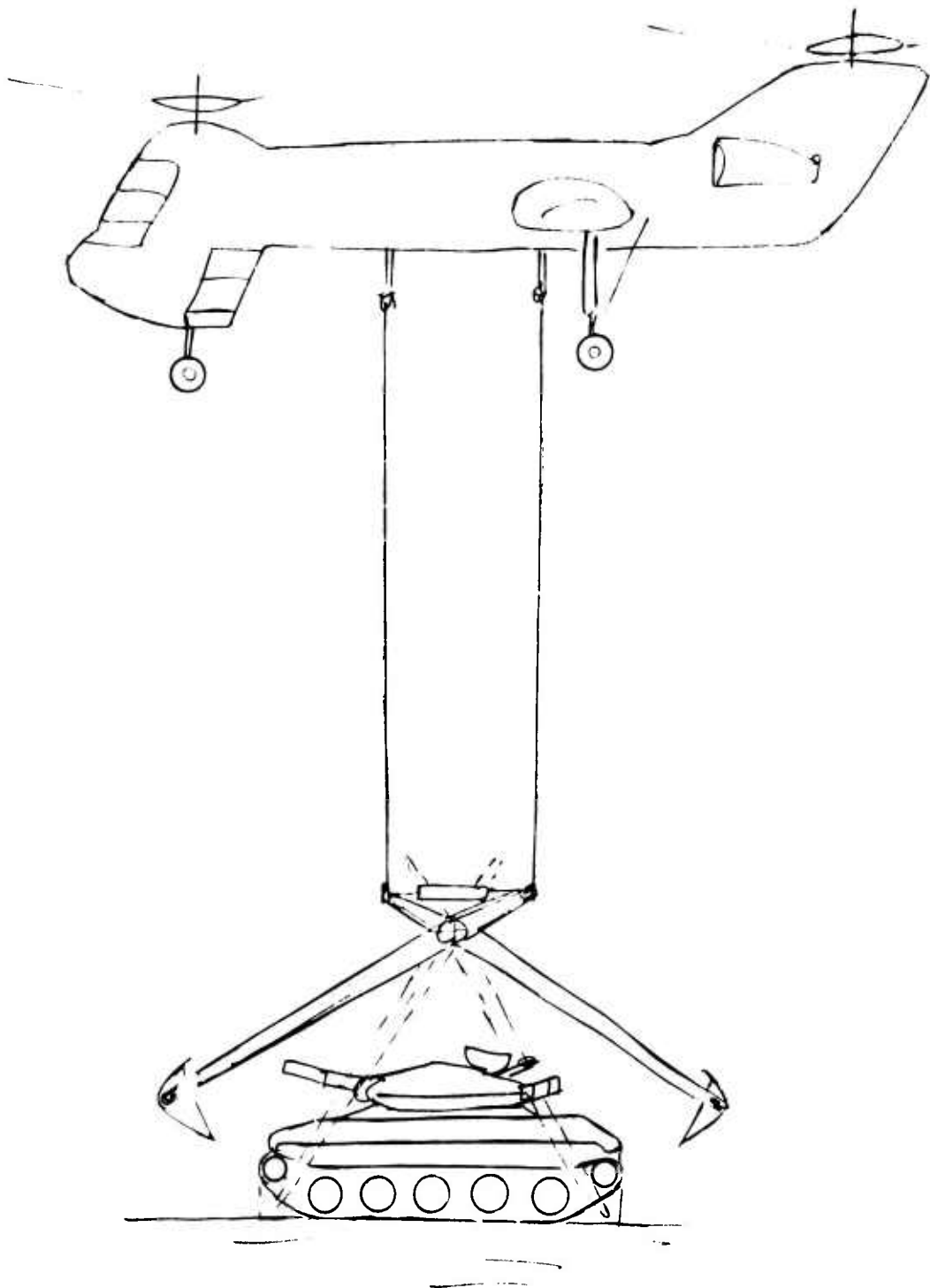


Figure 28. Forcep Automatic Load Acquisition System Operation.



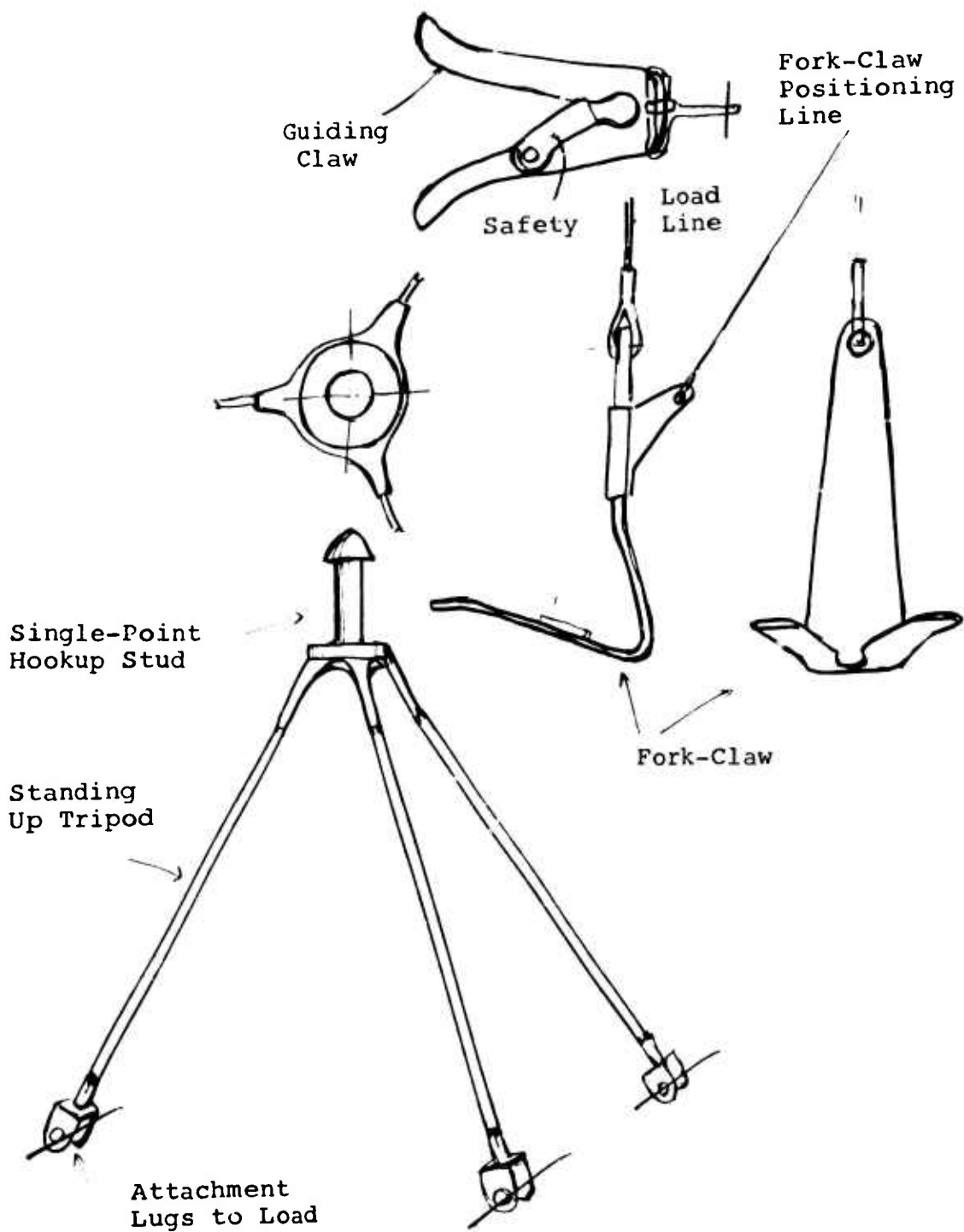


Figure 29. Lifting Stud/Fork-Claw HALAS System Conceptual Design.

fork design features of the load acquisition device will provide guidance and hookup engagement, allowing for position errors of the helicopter and acquisition device in the hookup operation.

The hookup engagement of the lifting stud by the fork-claw load acquisition device could be accomplished by two approaches. The hookup engagement could be accomplished by a slow, horizontal motion of the helicopter guiding the fork-claw acquisition device toward and into the lifting stud. The other approach would be for the hovering helicopter to achieve the hookup engagement by first positioning in the vicinity of the lifting stud and then by operating the maneuvering line attached to the fork-claw acquisition device for terminal hookup engagement.

The typical operation of the lifting stud/fork-claw HALAS system concept is illustrated in Figure 30. In Figure 30 a lifting stud on a tripod is attached to a typical howitzer type of weapon load for automatic acquisition by the fork-claw acquisition device. The efficiency of such an operation could be greatly increased by a ground-based operator-in-the-loop HALAS system especially in a bad weather environment and with poor visibility conditions coupled with a long sling cable in dynamic oscillation. Due to the simplicity of the lifting stud design and its versatility in adaptation to various major loads, this system concept appears to be quite promising.

#### 5.7 LIFTING STUD WITH SELF-GUIDING/HOMING RECEPTACLE HALAS CONCEPT

Another version of the automatic load acquisition device for hookup of the lifting stud is a self-guiding and terminal-homing receptacle. The receptacle has a funnel-shaped opening to be placed over the stud for guiding the stud to the clamping position. The load acquisition receptacle unit could be lowered by a single sling line with positioning guiding line or could be mechanized for a two-point hookup operation. The receptacle funnel opening is of large diameter to allow for positioning errors. The system design of the lifting stud with self-guiding/homing receptacle HALAS concept is illustrated in Figure 31.

The stud and erecting lifting support design is much the same as described in the previous section. The hookup receptacle unit is equipped with self-guiding and terminal-homing circular electromagnets placed at the funnel opening. On the base of the lifting stud, a disk-shaped permanent magnet could be incorporated to enhance the automatic hookup.

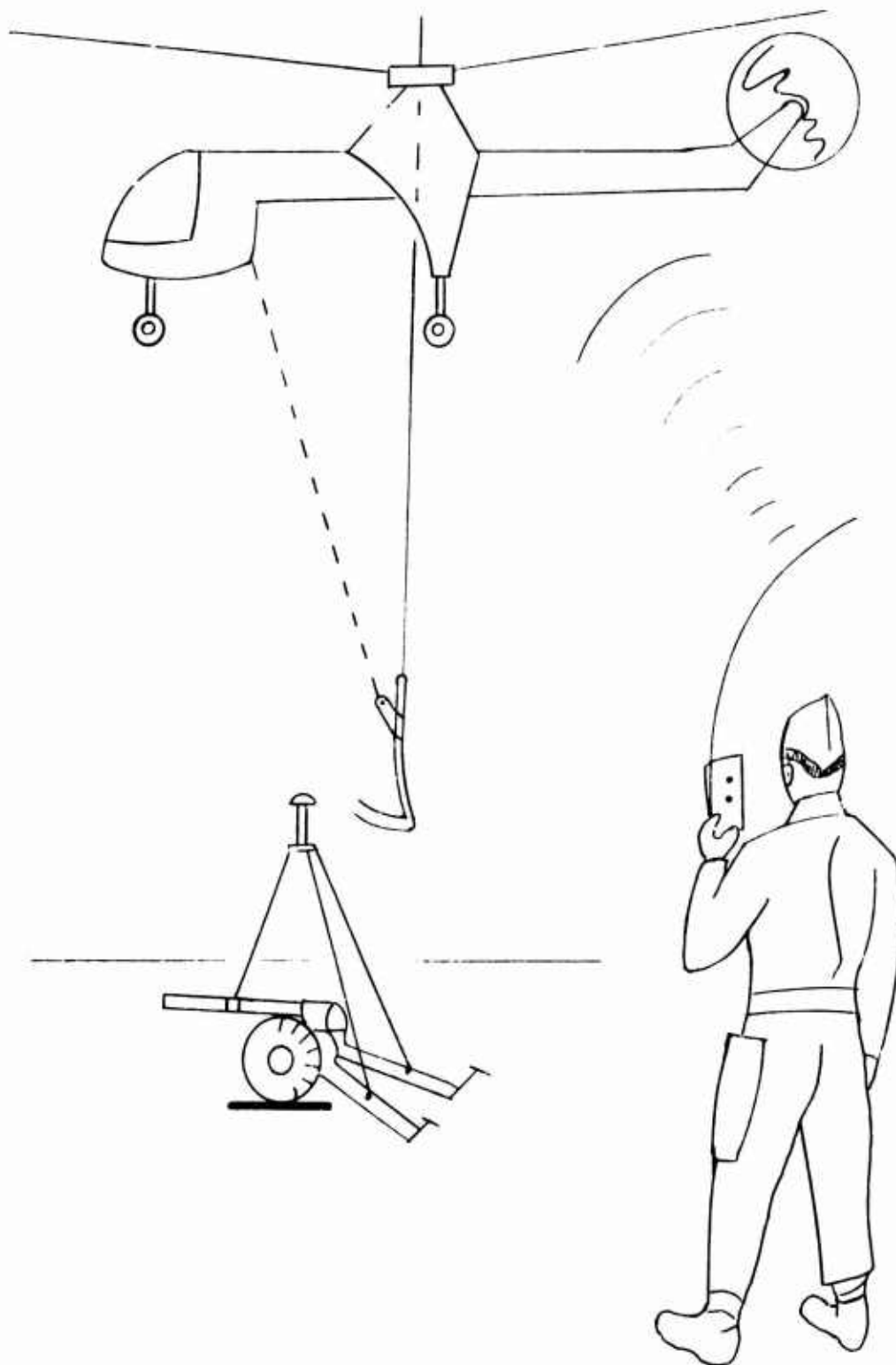


Figure 30. Typical Operation of the Lifting Stud/Fork-Claw HALAS System Concept.

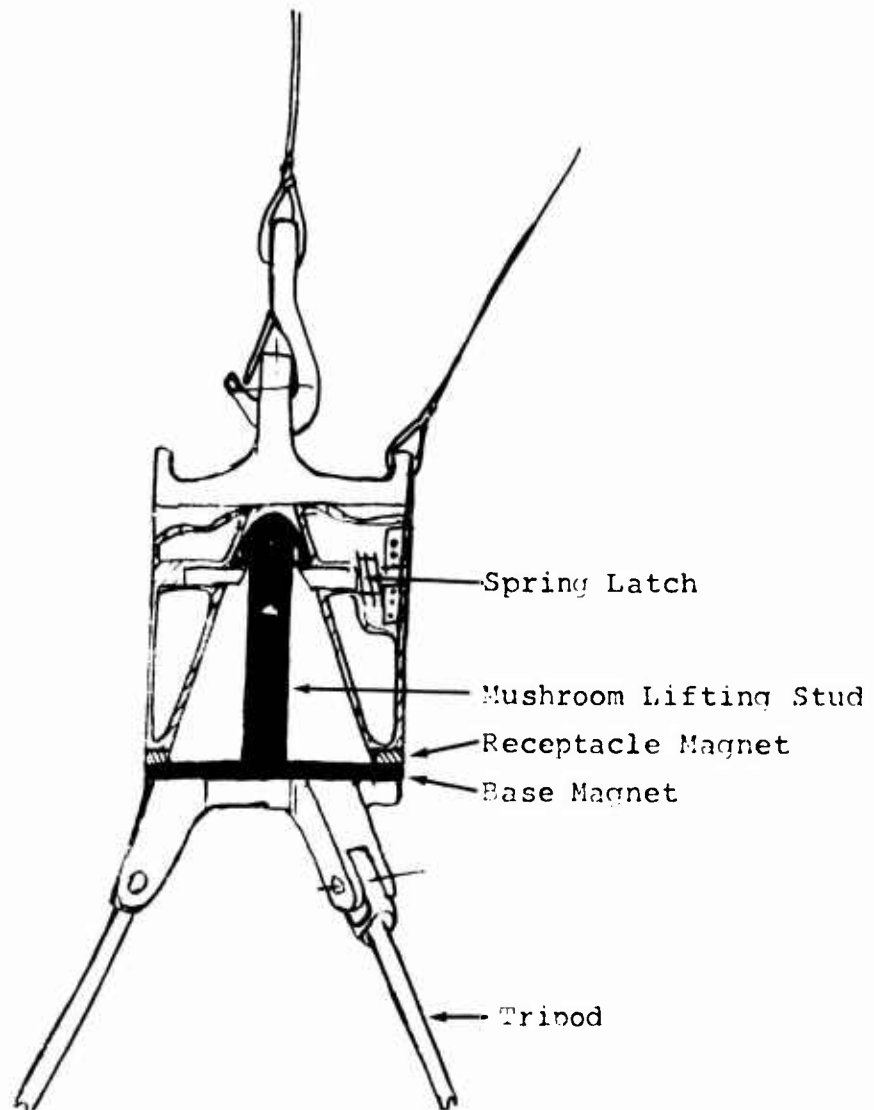


Figure 31. Lifting Stud With Self-Guiding/Homing Receptacle HALAS Conceptual Design.

Several ring-shaped circular magnets have been experimented for investigating the terminal link-up guiding capability of such a magnetic device. The results seem promising for the HALAS application. Once the lifting stud and receptacle are in place, spring-loaded prongs could be activated concentrically inward, locking the lifting stud in for lift-off. This engagement could be accomplished by activation of solenoids which overcome the spring force of the prongs. The electromagnetic mating ring on the receptacle opening could also be activated to assist this engagement.

The system operation of this HALAS concept is illustrated in Figure 32. To optimize the efficiency of this HALAS system concept, the helicopter must have positioning stability and precision hovering capability over the load position. Modern-day helicopters, and especially the heavy lift helicopters, possess the positioning hold and precision hover capability sufficient to make this HALAS system concept practical. The precision hover capability of the heavy lift helicopter together with the self-guiding and terminal-homing capabilities of the acquisition device will make the automatic hookup easy to achieve. The preparation required for the load to be airlifted is quite simple. For the application illustrated in Figure 32, the lifting stud with tripod support could be attached to the howitzer in a matter of a few minutes. This HALAS system concept could also be mechanized for two-point pickup of various major Army loads. Further analysis should be conducted; design variations and engagement mechanization are to be studied.

#### 5.8 APPLICATION OF TECHNOLOGY IN MAGNETICS FOR AUTOMATIC EXTERNAL LOAD ACQUISITION SYSTEM

Studies have been conducted to apply the technology in magnetism for automatic acquisition of helicopter external loads. It was found that magnetic technology could be utilized in the following three major areas for the HALAS designs:

1. Electromagnetic load handling devices
2. Terminal alignment and homing of the hookup engagement
3. The locking and unlocking mechanism for the hookup devices

Electromagnets have been used in the industry for hoisting various heavy equipment and steel material. Based on the results of recent investigation and the information supplied by a leading manufacturer, large lifting capability of the electromagnet system over the deadweight of the system is

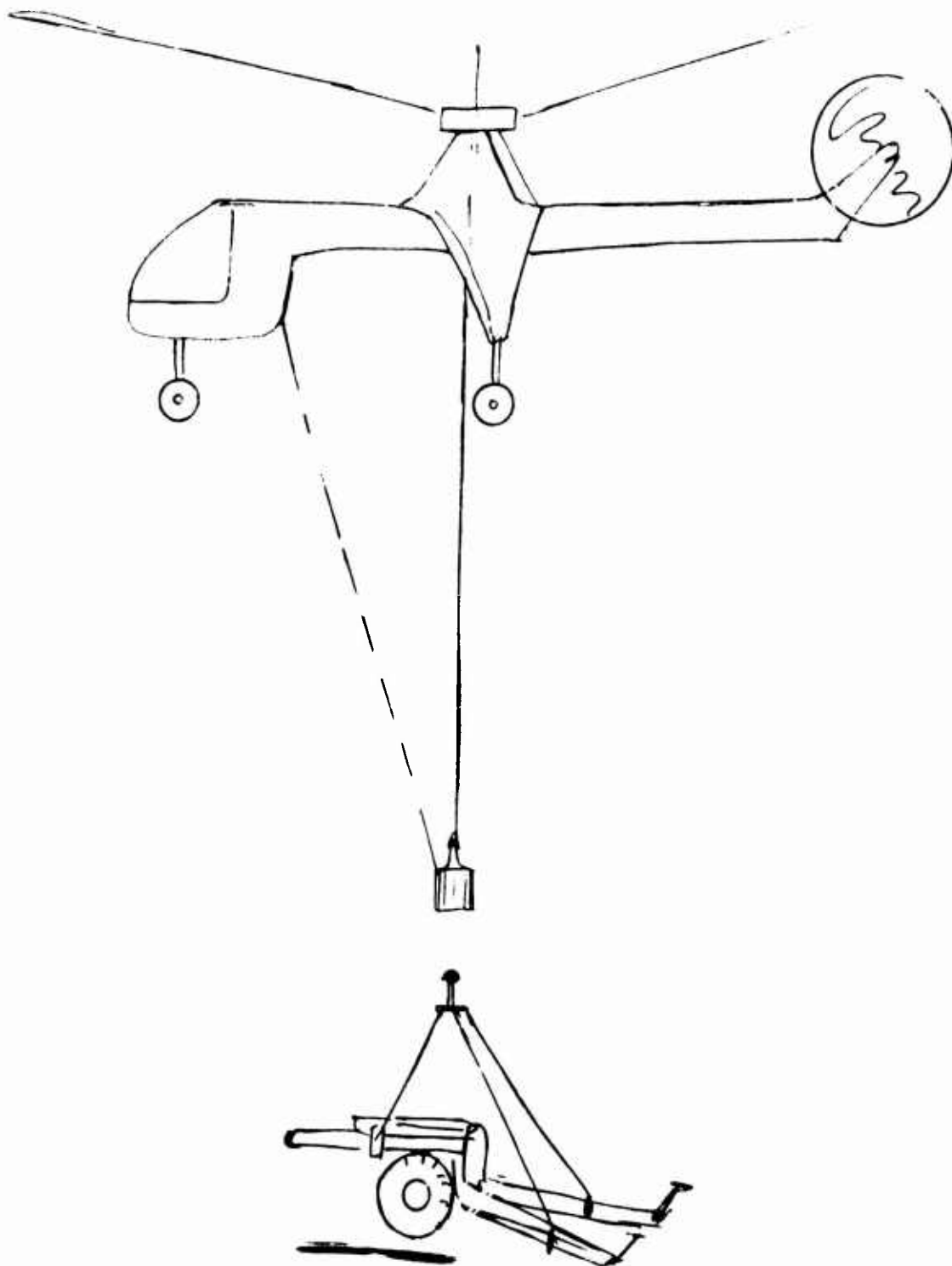


Figure 32. Application of the Lifting Stud With Self-Guiding/Homing Receptacle HALAS Concept.

practical and low in cost. One typical electromagnet that could be utilized for load handling devices weighs only about 570 pounds. It is a circular magnet of 20 inches diameter and 7.75 inches height. The maximum lifting capability is 25,000 pounds of load using 1,000 watts electricity. Modular rectangular electromagnets are also available. The rectangular electromagnets of 16 inches width by 80 inches length by 8 inches height, weighing 1600 pounds, have a maximum lifting power of 55,000 pounds (27.5 tons). The electrical requirement for this rectangular electromagnet is 2400 watts DC. The cost of the above-described circular electromagnets is only about \$1500. The maximum lifting power could be achieved provided that the surface of the load is smooth and has adequate thickness. As a general industrial practice, a margin of safety of 2 is normally applied.

Lifting capability versus the magnet weight for the above described circular electromagnets is about 44 pounds per pound of magnet weight. This factor is even higher for the 2-ton lifting electromagnets, which weigh only about 65 pounds, i.e., about 62 pounds per pound of magnet. This 2-ton lifting circular electromagnet is 8.62 inches in diameter and 4 inches thick. It takes 140 watts and costs only \$200.

Due to the electromagnets' high lifting capability, low system weight, low cost, and simplicity in mechanization for achieving a fully automatic load acquisition, further exploration of the use of electromagnets for HALAS application is recommended.

The following types of loads could be efficiently handled by the electromagnetic automatic load acquisition system:

1. Armor plates
2. Large steel tubing and bars
3. Large wire coils
4. Landing strip plates
5. Various types of gun barrels
6. Bridge float assemblies
7. Many types of bridge sections

The typical electromagnetic HALAS system concept is illustrated in Figure 33. This electromagnetic load acquisition system is fully automatic in that no lifting fixture or device needs to be attached to the load, and engaging and disengaging the acquisition device with the load are automatic.

As shown in Figure 33, two or four U-shaped electromagnets could be attached to an adjustable spreader beam. Circular electromagnets mounted on floating suspension could also be attached to the adjustable spreader. Depending on the

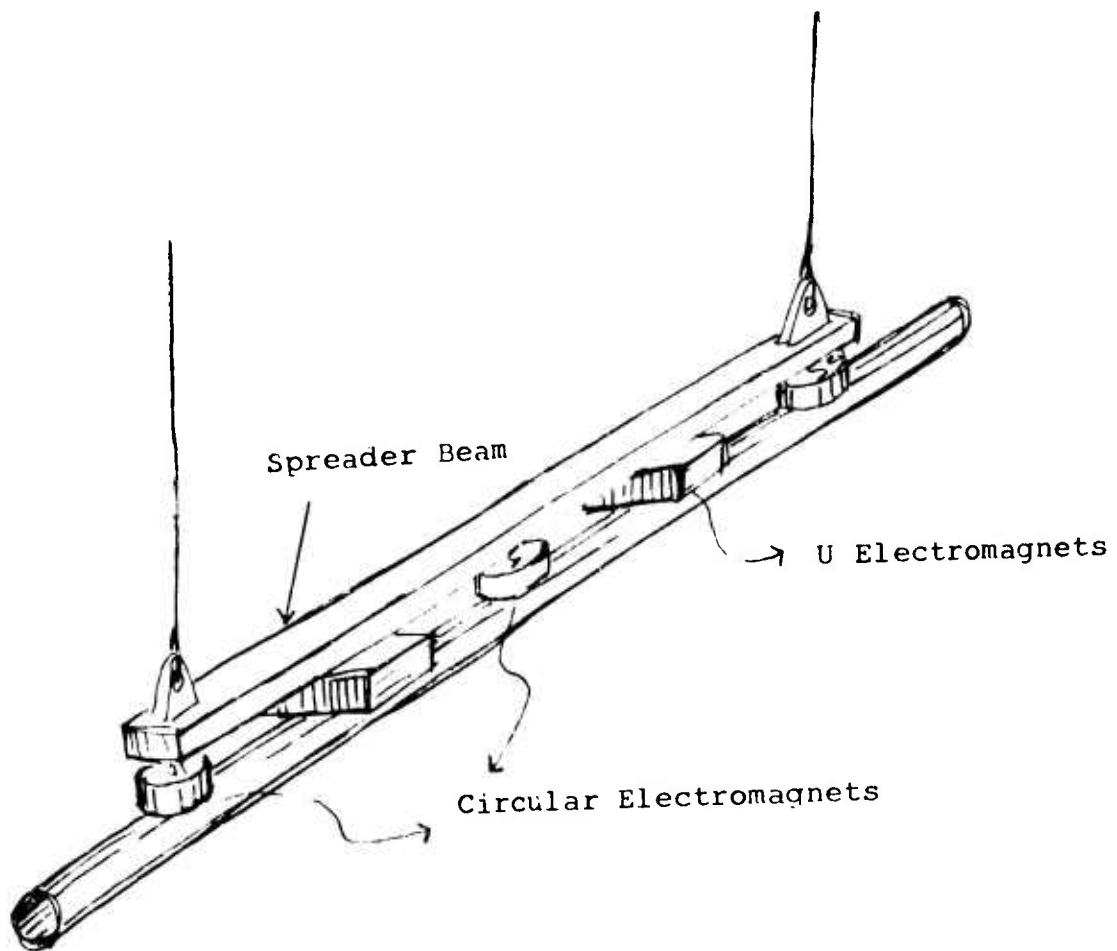


Figure 33. Typical Electromagnetic HALAS System Concept.



configuration of the loads to be airlifted, either the circular electromagnets or the U-shaped magnets could be activated for automatic load acquisition. The spreader frame with the electromagnets could be designed for handling large variations in the sizes and configurations of the above-listed loads. The design configuration of the magnets should also take into account the shear forces that may be present in an airborne system between the load and the magnet. The magnitude of the shear forces is a function of the sling and load configuration.

The application of the electromagnetic HALAS system concept should be further explored and analyzed.

#### 5.9 FULLY AUTOMATIC HELICOPTER LOAD ACQUISITION SYSTEM

Efforts have been directed in conceptual designs of two distinct types of automatic helicopter load acquisition systems:

1. For prepared Army loads - in this case, some type of lifting provisions will be attached to the loads to be airlifted prior to the automatic hookup.
2. For the unprepared loads - in this case, the load acquisition is fully automatic without prior preparation of the loads by attaching lifting provisions to the load to be airlifted.

The major preliminary design goals for both types of HALAS design concepts are:

1. Simplicity in design and operation
2. Low system cost
3. Versatility in handling different helicopter load types
4. Reasonable helicopter hovering time necessary in load engagement operation.

In this section a candidate design concept meeting the design goals for handling many types of Army helicopter loads in a fully automatic operation without preparing the load by attaching lifting provisions to the load prior to hookup is described. Most of the Army's heavy vehicles and tanks are equipped with padeyes as lifting provisions. The lifting padeyes on all of the medium and heavy Army tanks are well exposed and symmetrical. The popular medium and heavy Army tank group is selected for configuring the fully automatic HALAS design concept. The fully automatic HALAS design concept for

handling unprepared Army loads utilizes existing lifting provisions, padeyes and lifting rings as the load engagement terminals. Inasmuch as these terminals are used in the manual engagement of the lifting cables and hooks to the load, this fully automatic HALAS concept attempts to accomplish the same operation automatically. The description of the proposed fully automatic HALAS design concept is contained in the following sections:

5.9.1 System Concept Description

5.9.2 System Implementation

5.9.3 System Operation

5.9.4 Critical Discussion

5.9.1 SYSTEM CONCEPT DESCRIPTION

The fully automatic helicopter load acquisition system described in this section would employ the existing lifting provisions on the load for all the medium and heavy Army tanks. The lifting provisions are in the form of padeyes located about the four corners of the load. In the manual engagement, the hooks of the lifting cables are engaged with respective padeyes on the load. The manual process of the load engagement consists of a few elementary operations:

1. Reaching and grasping the hook of the sling cable
2. Seeking and locating the padeyes
3. Bringing the hook to the padeyes
4. Depressing or releasing the hook's safety catch
5. Attachment of the hook to the padeye

The proposed system concept could perform the above load engagement process automatically. The capability of the proposed system could be easily expanded to include all-weather day and night operation as well as load acquisition with long hoisting sling cables. For such a fully automated system with all-weather day and night capabilities, the proposed system is not overly complex as compared to the proposed lifting loop/tong-hook HALAS design concept for automatic acquisition of prepared Army loads. We believe that such a fully automated HALAS system design could be achieved with reasonable complexity and cost for handling all types of unprepared Army loads.

An approach to the development of such an automatic HALAS design concept consists of the following mental steps. In the first step, the crewman is removed from direct contact with the load to an imaginary position on an overhead rectangular spreader frame. The load acquisition spreader frame itself is suspended either by single-point, two-point or four-point sling suspension from the helicopter. The load acquisition spreader frame could be placed at a distance of approximately 6 feet above the tanks, providing adequate clearance between the load acquisition frame and the top of the tanks. In the next step, the imaginary crewman will be lying prone on the load acquisition frame. From such a position he can observe the load acquisition engagement process. Since four sling cables with hooks are generally required for airlifting a tank, it is proposed that there will be four sling cable lines attached to the four corners of the load acquisition spreader frame.

The question which can be asked at this point is: If the sling cables with hooks are lowered to the vicinity of the lifting padeye, how could the crewman improvise the necessary tools to make a remote engagement? There may be several solutions to this question, but the simplest device will consist of a single rod with a simple grip claw at the rod end. The rod arm with grip claw could easily guide the sling hook, a specially designed hook, to achieve the hookup into the lifting padeye at a distance of 5 or 6 feet from the spreader frame to the tank. Once the engagement of the sling hook to the lifting padeye is completed, the safety catch will be engaged and the guiding rod will be left attached to the sling hook but otherwise passive; that is, the guiding rod will not carry any load, which will be taken entirely by the sling cable of the spreader frame directly transmitted to the helicopter sling load hoisting cables. The final step will be to replace the imaginary crewman on the load acquisition frame and move up to the sling load controlling cockpit in the helicopter, where he can remotely control the guiding rod attached to the corners of the load acquisition spreader frame. The guiding rod will be designed with some telescoping capability in extending and contracting within a short distance. Longitudinal and lateral motion of the guiding rod will be provided by either small hydraulic jacks or electric screw jacks. The three degrees of freedom of the guiding rod are thus easily provided. With simple load stabilization and alignment grip pads to align and position the load acquisition spreader frame with the load, together with the incorporation of a simple display, the automatic hookup by the use of the hook guiding rod could be achieved fairly effectively. The implementation of the full automatic HALAS design concept is described in the next section.

### 5.9.2 SYSTEM IMPLEMENTATION

Figure 34 illustrates the fully automatic HALAS design concept. The system design consists of a rectangular load acquisition spreader frame, with four load lifting sling cables, four extendable hook guiding rods, and two load stabilizing gripping pads. The purposes of the load acquisition spreader frame are: (1) spreading of load lifting cables to four lifting cables; (2) providing a base for mounting the hook guiding rods and gripping pads; (3) providing a base for mounting a small TV camera for close viewing of the engagement operation. The size of the frame member has been analyzed and optimized for the tank group and is determined by the compression loads that can be carried by one universal frame for handling all types of medium and heavy Army tanks with minimum size and weight. The transverse frame members act as a spreader beam. The longitudinal spreader members will take compression load components when the distance between the fore-and-aft load lifting padeyes are shorter than the longitudinal frame length between the fore-and-aft sling cables of the spreader frame. A 1-foot extension of the spreader frame is provided fore and aft of the load acquisition frame to enable the hook guiding rods to have adequate clearance to maneuver in guiding the sling hook into the lifting padeyes for engagement.

A group of Army medium and heavy tanks is selected to evaluate the feasibility and implementation of this fully automatic HALAS design concept: tank models M108, M551, M113, M110, M107, M548, M106 and M125. The basic spreader frame length is optimized for the tank group to be 192 inches longitudinally and 100 inches laterally. Based on the selected spreader frame dimensions, the longitudinal and lateral position envelopes of the lifting padeyes on the selected tank loads are established. The padeye position envelopes provide the extent of guiding movements necessary in the longitudinal and lateral plane. The locations of the lifting padeyes of the tank groups, as viewed from the front of the loads, give the angular movement and the vertical length required for the guiding rods to reach the lifting padeyes of the tank, assuming a 2-foot clearance between the spreader frame and the top of the load. The longitudinal side view of the lifting padeye positions of the tank group establishes the hook guiding rod actuator length and stroke requirements. Based on the preliminary design analysis, it is shown that the hook guiding rod and its actuator are reasonably short and light in weight. It is estimated that a 7-foot hook guiding rod with about 2 to 3 feet extension is sufficient to handle all the tank configurations.

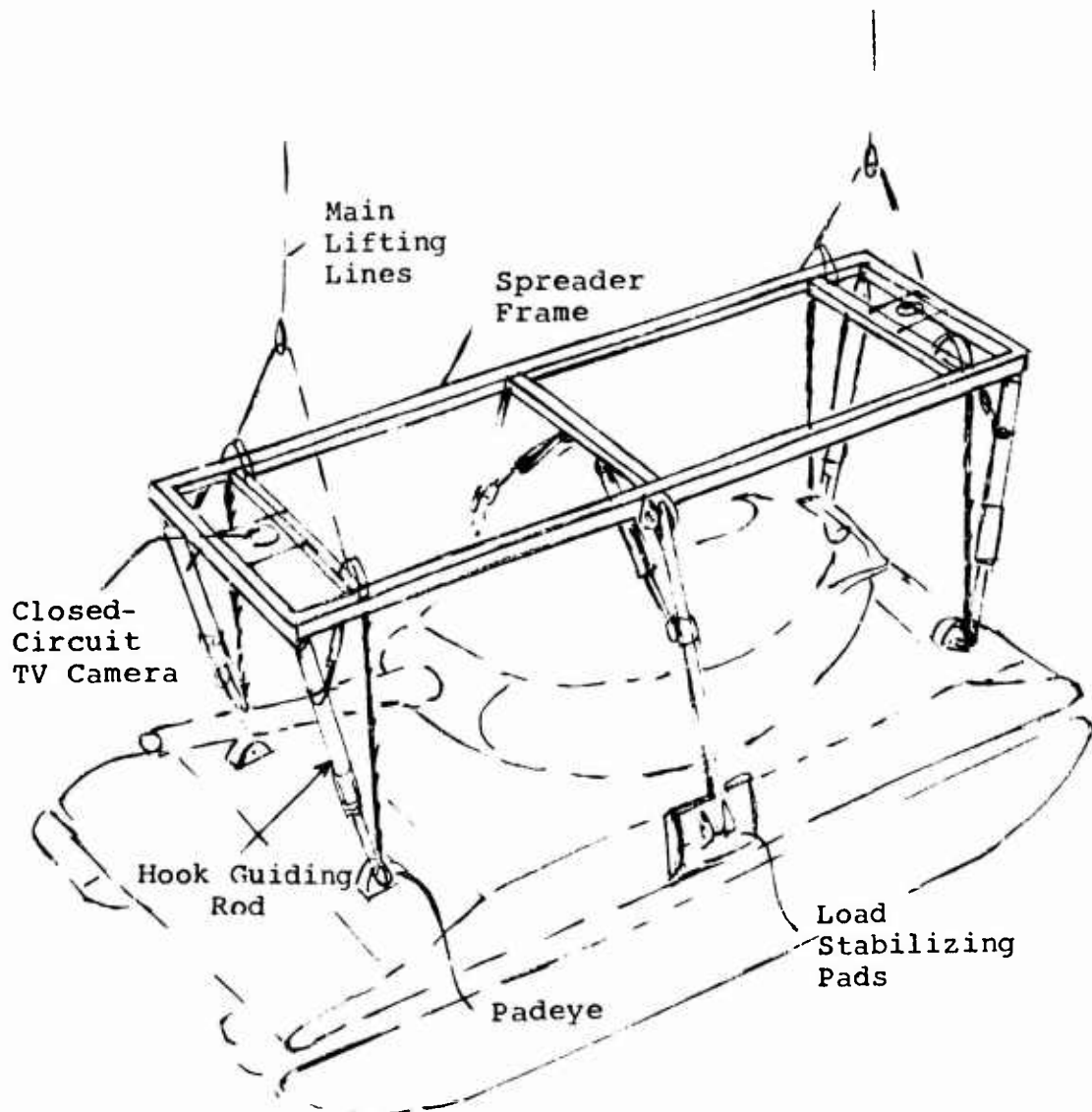


Figure 34. Fully Automatic HALAS Design Concept for Unprepared Army Loads.

The hook guiding rods are pivoted at the corners of the two auxiliary frames fore and aft of the basic spreader frame. The lower ends of the hook guiding rod are connected to the specially designed acquisition hooks connected to the load-carrying sling cables. The conceptual design of the hook guiding rods with actuators and specially designed load acquisition hooks is illustrated in Figure 35. The upper pivot points of the hook guiding rods are of the ball-joint type.

The hook guiding rods, which are about 7 feet long, have 2- to 3-foot extensions made up of an actuator of either the hydraulic or electric screwjack type. Thus the hook guiding rods are capable of controlling the movement of the sling hook within a considerable spatial volume presented previously. At the far end of the extendable piston rod of the hook guiding rods, a specially designed load acquisition hook is attached as shown in Figure 35.

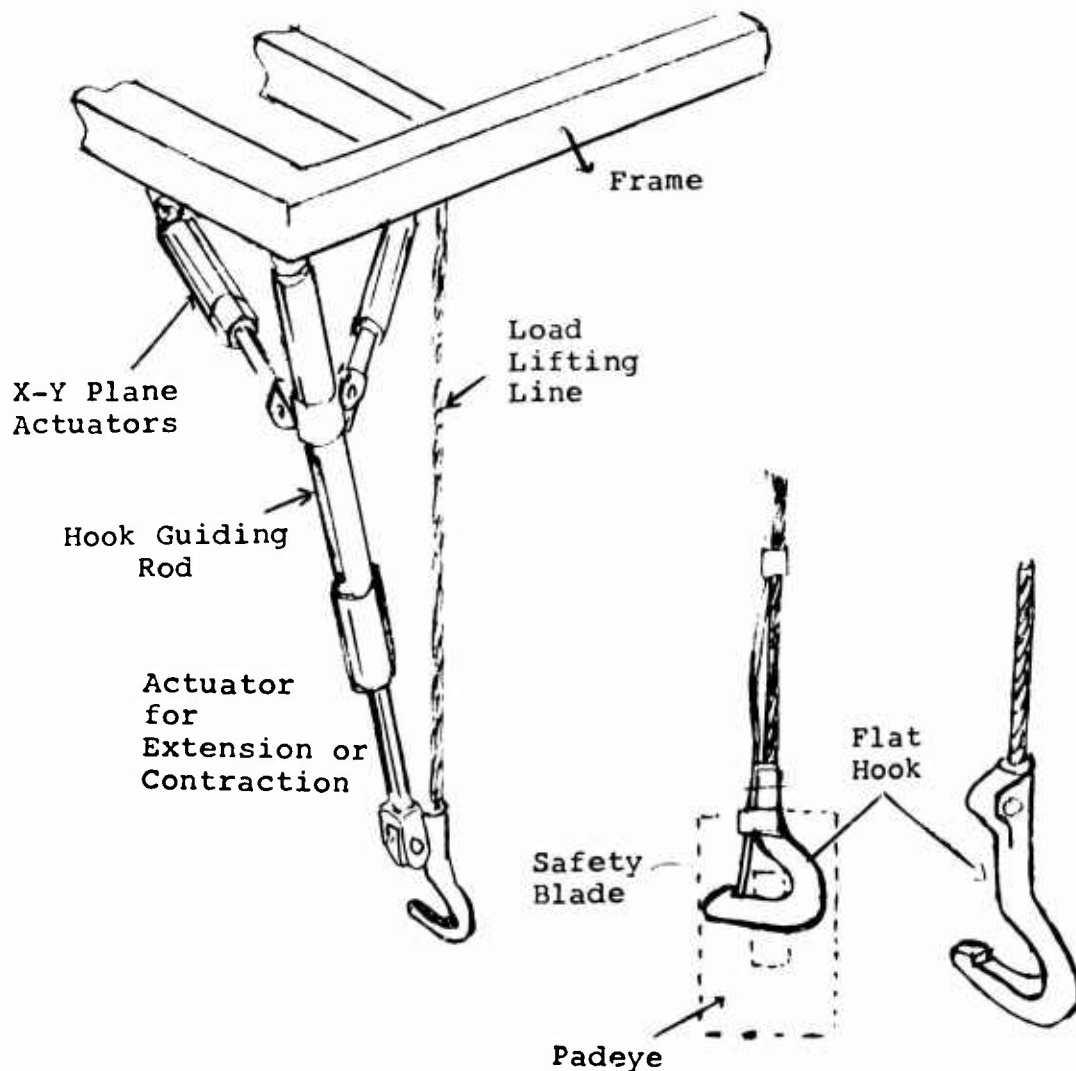


Figure 35. Conceptual Design of Hook Guiding Rods With Actuators and Specially Designed Load Acquisition Hook.

The controls of the hook guiding rods in the helicopter would be of a single joystick type. It is entirely feasible that the engagement could be accomplished in pairs such as the front and the rear padeye pairs. Therefore, individual guidance of the hook to the padeye can be avoided to shorten the speed of engagement. By providing some simple display, the load acquisition hookup could be accomplished with minimum control movements by the load-control crewman efficiently.

After the engagement of the sling hook to the lifting padeye of the load, the actuators of the particular hook guiding rod will be set to free-floating. This provision will prevent the jacks from taking any force of the load during lift-off and flight transportation.

The hooks, for a remote engagement with the lifting padeves, are of the flat type, curved properly for the padeve with a long horizontal lower hook for sliding in and out sidewise of the padeye. Special safety locking catches will spring out to lock the hooks over the padeves when the hookup is completed.

The electric or hydraulic system will be mounted on the spreader frames. The command signal to the hook guiding rods and jacks will be electrical and generated by the control logic of the load control systems in the helicopter. The disengagement of the device from the load will also be fully automatic. The sling hooks will be disengaged and moved away from the lifting padeves by the hook guiding rods controlled by the load-control crewman. The total weight of the proposed automatic load acquisition system is estimated to be about 650 pounds, which includes the load acquisition frame weight of about 200 pounds and the hydraulic system weight of about 400 pounds.

### 5.9.3 SYSTEM OPERATION

Operation of this automatic load acquisition system will require the load-control crewman in the helicopter to first lower the load acquisition device in the vicinity of the load to be airlifted. The pilot or load-control crewman will then maneuver the helicopter to place the load acquisition frame over the load similar to the load engagement procedure for picking up the containers. By using a closed-circuit TV system with small cameras mounted on the fore-and-aft transverse frame, the overall load, the lifting padeye, and the hookup operation will be easily visible in all-weather, day-or-night, all-visibility conditions due to the close proximity of the load acquisition frame to the lifting padeye. In the worst case for the medium and heavy tank loads, the load acquisition frame with the TV viewing camera will not be greater than 7 feet from the lifting padeyes on the tank, including

the 3-foot clearance between the spreader frame and the top of the tank.

Through the use of simple display, the load-control crewman could easily position the load acquisition frame with respect to the load within the operating range of the hook guiding rod. As the load acquisition frame is stabilized and aligned by the engagement of the stabilizing pads, the load-control crewman could efficiently hook up the pad-eye by moving the hook guiding rod while viewing the operation through a simple TV display.

Under ideal viewing conditions of bright daylight, some form of simple optical aid could be configured and mounted on the helicopter without the use of a closed-circuit TV system on the load acquisition frame. Under poor visibility and bad-weather conditions, especially hoisting the load with long sling cables, a closed-circuit TV system could be utilized to overcome all the visibility problems for very little cost and weight penalty using the current state-of-the-art technology.

A joystick control is most suitable for controlling the operation of load engagement. The position of the hook guiding rod could be controlled in the longitudinal and lateral axes in the horizontal plane as well as the extending and contracting motion along the axis of the hook guiding rod itself. To improve the identification of the lifting padeyes and acquisition hooks during the load engagement process, these parts could be painted with iridescent paint or properly taped with illuminating tape to provide visual aids in day, night, and all-weather visibility conditions.

#### 5.9.4 CRITICAL DISCUSSION

The proposed fully automatic helicopter load acquisition system possesses all the capabilities of an ultimate system. The capabilities and requirements of the ultimate system should include the following:

1. Capable of handling all unprepared Army loads
2. Universally applicable to all Army loads
3. Capable of operating in all-weather, day, and night visibility conditions
4. Capable of effective load engagement in hoisting with long sling cable
5. Have short load engagement time



6. Have reasonable cost, weight, and system complexity.

It does not seem likely that any automatic helicopter load acquisition device that satisfies all the above-stated capabilities and requirements could be as simple as a conventional hook with some mechanical lifting provision. The system complexity is obviously reduced considering an automatic load acquisition system for handling prepared loads as shown by the proposed lifting loop and tong-hook HALAS concept. The automatic load acquisition system for handling prepared loads might not be cost-effective if the overall cost and logistic implications are considered, involving all types of lifting attachments required for all types of loads and the operational cost of the personnel involved in preparing the loads. The tradeoff between these two approaches, considering their operational advantages and overall system cost, is to be studied.

The fully automatic helicopter load acquisition system described in this section is configured assuming that the current lifting provisions on the selected tank groups could be utilized for helicopter air transportation. One important possible development to be considered is that the present lifting provisions on many current Army loads might not be adequate strengthwise to be utilized for air transportation by helicopter; it is inevitable that these inadequate lifting provisions on some of the Army loads will have to be redesigned and replaced. It appears to be advantageous to develop a universal mechanical coupling device suitable for automatic helicopter load acquisition in line with future Army air transportation requirements. The redesigned lifting provisions on the loads should incorporate features suitable for universal automatic load acquisition operation. We are planning to verify the feasibility of the presented concepts and to study various possible means to improve the efficiency of hookup for the presented fully automatic helicopter load acquisition system that requires no preparation prior to airlifting.

5.10 MAGNETIC HOOK/LIFTING RING HALAS CONCEPT

5.10.1 SYSTEM CONCEPT

The various design concepts presented previously could be grouped in two major categories:

1. Automatic load acquisition through the use of a lifting attachment to the existing lifting provisions of the Army loads prior to airlifting.

2. Automatic load acquisition utilizing the existing lifting provisions of the Army loads without preparation of the loads prior to airlifting.

Reappraisal of these two major system approaches of HALAS concepts led to the formulation of a conceptual system approach which combines the features of the above two approaches. Although this system approach requires preparation of the load to be airlifted by attaching a lifting adapter to the existing lifting provisions of the load for automatic load acquisition operation, it is not necessary to remove the lifting adapter after load delivery or for subsequent airlifting operation. This one-time preparation of the load will enable the load to be airlifted automatically without any further preparation of the load for airlifting.

The proposed magnetic hook/lifting ring HALAS concept combines the above two conceptual system approaches. After attachment of the lifting adapter to the existing lifting provisions of the Army loads, the loads could be automatically acquired similar to handling unprepared loads. The important questions posed here are the following:

1. What kind of interfacing hardware, that is, the acquisition device between the hook and the lifting provisions, could achieve automatic coupling without complex mechanization and going through the "thread and needle" operation?
2. How can the manipulator be eliminated without compromising the hookup capability?

In this proposed concept, an adjustable frame discussed in Section 5.10.3 will be utilized for adjusting the spacing over the lifting provisions of various loads so that the load acquisition hook could be placed in the vicinity of the lifting provisions as the spreader frame is properly placed over the load without using manipulators. A specially designed two-way hook with electromagnetic lifting ring acquisition device is attached to the end of the hook rods. The hook rods are attached to the four corners of the adjustable spreader frame. Lifting rings of appropriate size are to be attached to the existing lifting provisions on the various loads such as the lifting padeyes on the tank. The magnetic hook/lifting ring HALAS concept is illustrated in Figure 36.

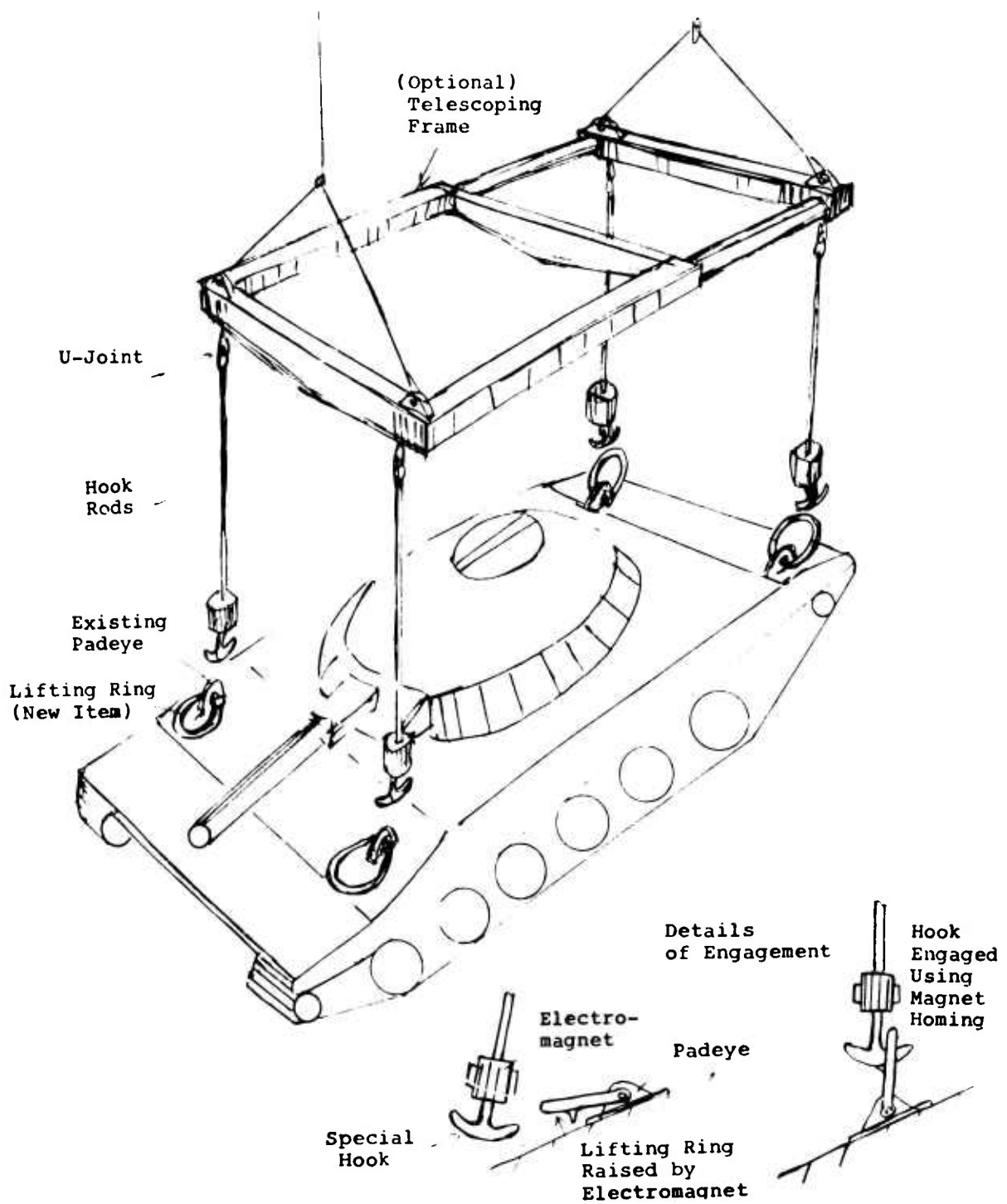


Figure 36. Magnetic Hook/Lifting Ring HALAS Concept.

The key design features of the system are as follows:

1. Oversized lifting rings are to be attached to the existing padeyes or other lifting provisions on the load. The attached lifting rings are free to move up and down, fore and aft, pivoted about the axis of the padeye in a fashion similar to that of the lifting shackles on the front bumper of typical Army trucks.
2. The specially designed two-way hook has a flat-bottom hook lip. The fore-and-aft hook axis will be placed in line with the longitudinal axis of the load.
3. The hook rods are attached to the corners of the adjustable spreader frame by means of U-joints and are arranged in such a way that the fore-and-aft hook axis will always be aligned approximately along the longitudinal axis of the load, yet it could move in all directions under the U-joint. An electromagnetic device is placed above the hook such that the magnetic flux pattern will attract the attached lifting rings on the padeyes in both the fore and aft positions.
4. A special snap-in safety hook design will be integrated into the load acquisition hook. This snap-in safety hook could be operated either mechanically or electromechanically for releasing the load and could provide spring loaded free lock-in feature.

The operation of the magnetic hook/lifting ring HALAS concept is as follows. The adjustable load acquisition frame is lowered to the vicinity of the padeyes on the load. It is assumed that the helicopter with the load acquisition frame could be positioned over the load within 1 foot of the padeyes on the load in vertical, longitudinal, and lateral positions. This accuracy requirement is comparable to that of the heavy lift helicopter in container load acquisition by utilizing a specially designed container acquisition frame. As the magnetic hook is placed within 1 cubic foot of the lifting provision with the lifting ring attached, the electromagnetic ring attracting device will be activated. Due to the magnetic flux pattern of the electromagnets, the lifting rings will be lifted and attracted to the magnets. The hooks could then engage the lifting rings.

A special snap-on safety hook is currently being designed for the application of this automatic HALAS concept.

### 5.10.2 FEASIBILITY MODEL TESTING

In order to check out the feasibility of the magnetic hook/lifting ring HALAS concept, a scaled model made of a single rod with flat hook and a permanent magnet was assembled. Then a scaled model of the load acquisition frame and four rods with hooks and lifting ring attracting magnets was assembled. The scaled feasibility model for testing the magnetic hook/lifting ring HALAS concept is illustrated in Figure 37. The small permanent magnet attached to the hook and rod has been proven to be effective in attracting the lifting ring to achieve a hookup. The padeyes and the attached lifting rings were fabricated from ferrous wire. The four padeyes with the lifting rings were then attached to a plate simulating the lifting padeyes on a typical tank configuration. A suitable length of thin wire was used to suspend the load acquisition frame from a horizontal bar simulating the helicopter.

To operate the system, the simulated tank with lifting padeyes and attached lifting rings was placed on the floor; the acquisition device was lifted by using the suspension bar, and was brought to position over the padeyes simulating the hovering helicopter in the load acquisition operation. By placing the two-way hook in the vicinity of the lifting rings in such a distance equivalent to within 1 cubic foot of dispersion volume in the true life situation, it was shown that the lifting rings were attracted by the magnet and the hookup could be easily accomplished. The magnetic attraction of the magnetic hook was also found to be beneficial in damping some initial random oscillations of the hook rods and in providing the homing guidance for the coupling of the hook and the lifting rings. The process of hooking up of all four hooks with the lifting rings was surprisingly fast. The dwell times for the hookup range from 10 to 30 seconds.

### 5.10.3 DESIGN OF ADJUSTABLE LOAD SPREADER FRAME FOR MAGNETIC HOOK/LIFTING RING HALAS APPROACH

There are two design approaches to accomplish hookup by the hook rod. One approach is to use a fixed rod spreader frame with length optimized for various groups of loads. The hook arm would then be adjustable in the x-y horizontal plane by hydraulic actuators attached to the hook rod and the spreader frame, similar to the design approaches for the manipulator load acquisition system concept proposed previously. If we are to eliminate the hydraulic actuator and to make the load acquisition system operate in a passive mode, then the load acquisition frame will have to be made adjustable in order to handle various loads.

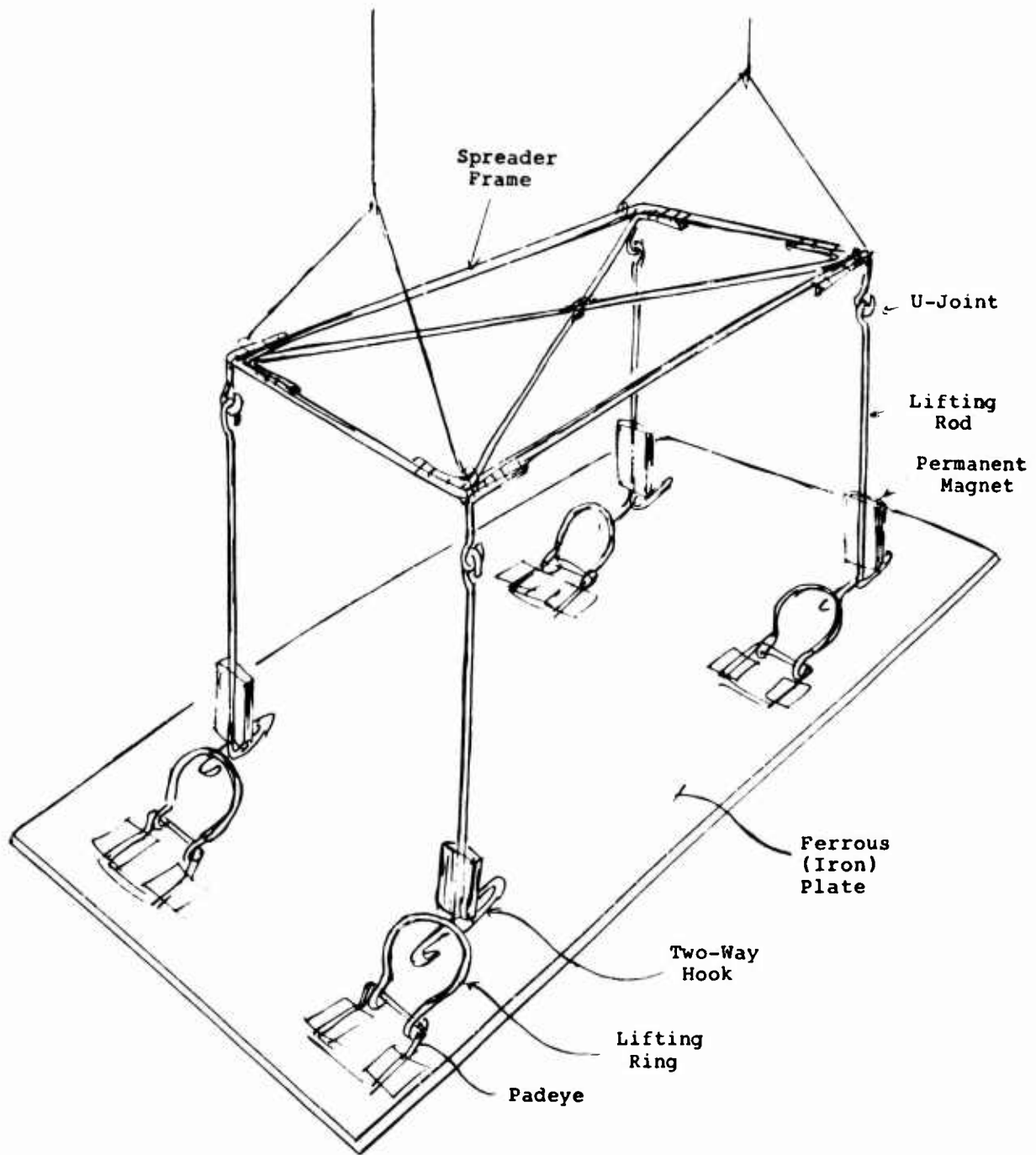


Figure 37. Feasibility Model Testing for Magnetic Hook/Lifting Ring HALAS Concept.

One conceptual design approach for such an adjustable spreader frame design is illustrated in Figure 38. This adjustable spreader frame consists of a basic frame and an extendable frame in the longitudinal direction. The lateral adjustment of the lifting hook rods is made internally. The adjustment of the longitudinal and transverse lifting hook rods' position is accomplished by screw jack mechanization powered by an electric motor. The extendable portion of the frame and the crosswise beam is connected in such a way that will prevent binding due to uneven telescoping drive of the longitudinal frame as shown in Figure 38.

The longitudinal beam length, transverse beam length, and hook arm length requirements are tabulated in Table 2 for typical tank and truck configurations. As seen in Table 2, the maximum and minimum longitudinal beam lengths are 267 and 146 feet. The maximum and minimum of the transverse beam length are 100 and 32 feet. The length of the hook rods from the spreader frame to the lifting provisions of various loads should be no greater than 111 and no less than 51 feet. The above hook length requirements are established assuming a 2-foot clearance between the top of the loads and the spreader frame.

#### 5.10.4 APPLICATION OF MAGNETIC HOOK/LIFTING RING HALAS CONCEPT

The proposed magnetic hook/lifting ring HALAS concept could also be applied to the automatic acquisition of typical Army trucks. Slight modification or preparation of the typical trucks is necessary. The attachment of the lifting adapter to the existing lifting provision between the rear drive wheels beneath the truck bed is a mandatory preparation. The design of such a lifting adapter is described and discussed in Section 5.10.3. Larger shackles will also be needed to replace those currently attached to the front bumper of the truck. These modifications described above are relatively simple to implement. The lifting sling adapter for the rear lift point and the oversized lifting shackle on the front bumper could be designed as a one-time permanent modification of the load. With such preparation, the truck would then be suitable for automatic acquisition by the magnetic hook/lifting ring HALAS approach, or by the previously presented active arm HALAS concept. The distance between the pickup points generally varies for different load types. The overall spacing of all the pickup points varies for different types of trucks. Such variation will be accommodated by using the adjustable load spreader frame as described in Section 5.10.3 for use in conjunction with the magnetic hook/lifting ring HALAS concept in handling various types of loads.

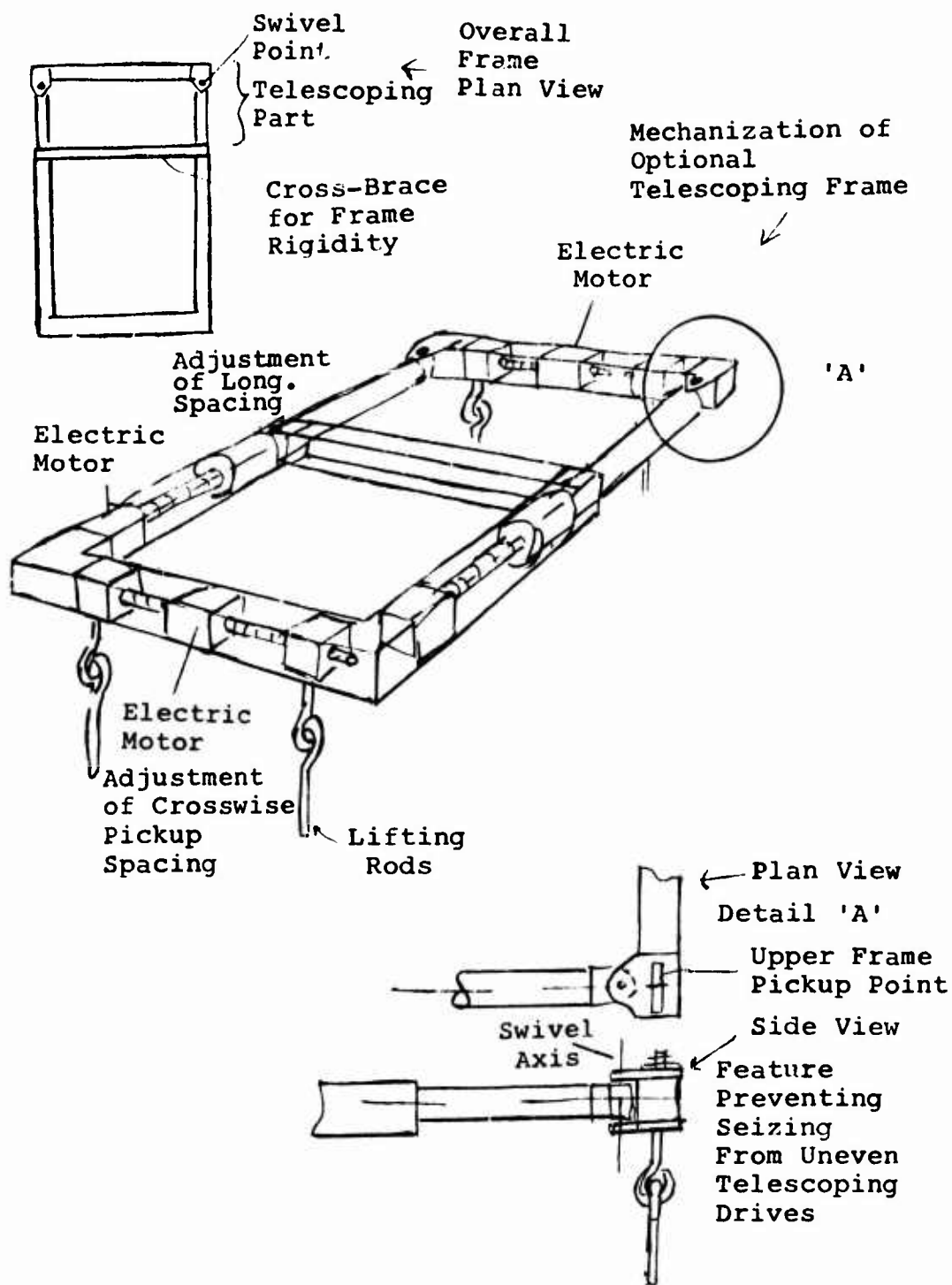


Figure 38. Design of Adjustable Load Spreader Frame for Magnetic Hook/Lifting Ring HALAS Concept.



TABLE 2. LONGITUDINAL AND TRANSVERSE BEAM LENGTH REQUIREMENT FOR THE ADJUSTABLE SPREADER BEAM DESIGN						
Model		Weight In Pounds	Longitudinal Beam $L_L^*$	Transverse Beam $L_T^{**}$	Hook Rod Length	
Tanks	Trucks				Front	Rear
M108		40,087	221	93	90	78
M551		33,460	190	75	69	64
M113		23,270	146	89	54	51
M110		58,000	231	89	85	51
M107		62,000	231	100	85	51
M548		26,000	190	71	55	87
M106		25,100	146	89	54	51
M125		23,800	146	89	54	51
	M220	15,035	197	32	91	91
	M9	14,430	192	32	78	78
	M101	21,000	241	32	111	111
	M35	13,200	206	32	93	100
	M215	14,870	184	32	91	93
	M55	24,250	267	32	101	100
	M123	28,940	228	38	69	69
<p>* <math>L_L</math>      Max 267      Min 146</p> <p>** <math>L_T</math>      100      32</p> <p>Longitudinal beam length equal to the longitudinal distance between the lifting provisions of the load.</p> <p>Transverse beam length equal to the transverse distance between the lifting provisions of the load.</p> <p>Hook rod length is the length of the hook rod from the load acquisition frame to the front and rear lifting provisions of the load.</p>						

In operation, as illustrated in Figure 39, the spreader frame with the lifting hooks will be lowered to the truck to be air-lifted. By positioning the load acquisition frame within 1 cubic foot with respect to the lifting provisions of the load, the electromagnetic lifting ring attracting device will be activated to attract the lifting ring and accomplish the hookup. In delivering the load, the electromagnet will be deactivated and the safety lock will be opened for release of the load either mechanically or electromechanically. Thus, the lifting rings of the load will be unhooked automatically for load release.

#### Design of Lifting Adapter to the Existing Lifting Provision Between Rear Drive Wheels for Typical Trucks

From the automatic load acquisition standpoint, the critical problem for handling Army trucks is the rear-end hookup engagement. Most Army trucks have two driving axles at the rear driving the four wheels. The two lifting points of the rear of the truck are placed on the axle assembly, reachable only beneath the truck bed and between each pair of rear wheels. The front end of the truck is equipped with lifting shackles hanging over the bumper.

The current method of manual hookup by attaching the lifting sling to the rear lifting provisions between the wheels underneath the truck bed is not problematic, but it is very inconvenient and inefficient for the hookup operation. For achieving the automatic hookup, the engagement of the rear lifting points of the truck presents a very difficult problem. Any automatic acquisition device lowered from the helicopter will have great difficulty reaching under the vehicle chassis and between the driving wheels beneath the truck bed. To facilitate automatic hookup, all lifting points should be made visible and unobstructed from the top.

Therefore, the important step which must be taken in making the trucks suitable for automatic engagement using the current existing lifting provisions is to bring the rear lifting provisions outside the hidden positions. Two approaches are suggested in this report as follows.

Lifting adapters such as the one illustrated in Figure 40 could be used for this purpose. The rear lifting adapter for the trucks consists of an adapter rod with fittings that can be attached to the existing lifting points of the truck between the wheels. The rear lifting adapter will be supported by a folding jack assembly that will keep the adapter fairly close to the corner of the truck bed without actually attaching to the truck bed. Lifting rings will be attached to the upper end of the lifting adapter. Depending on the automated

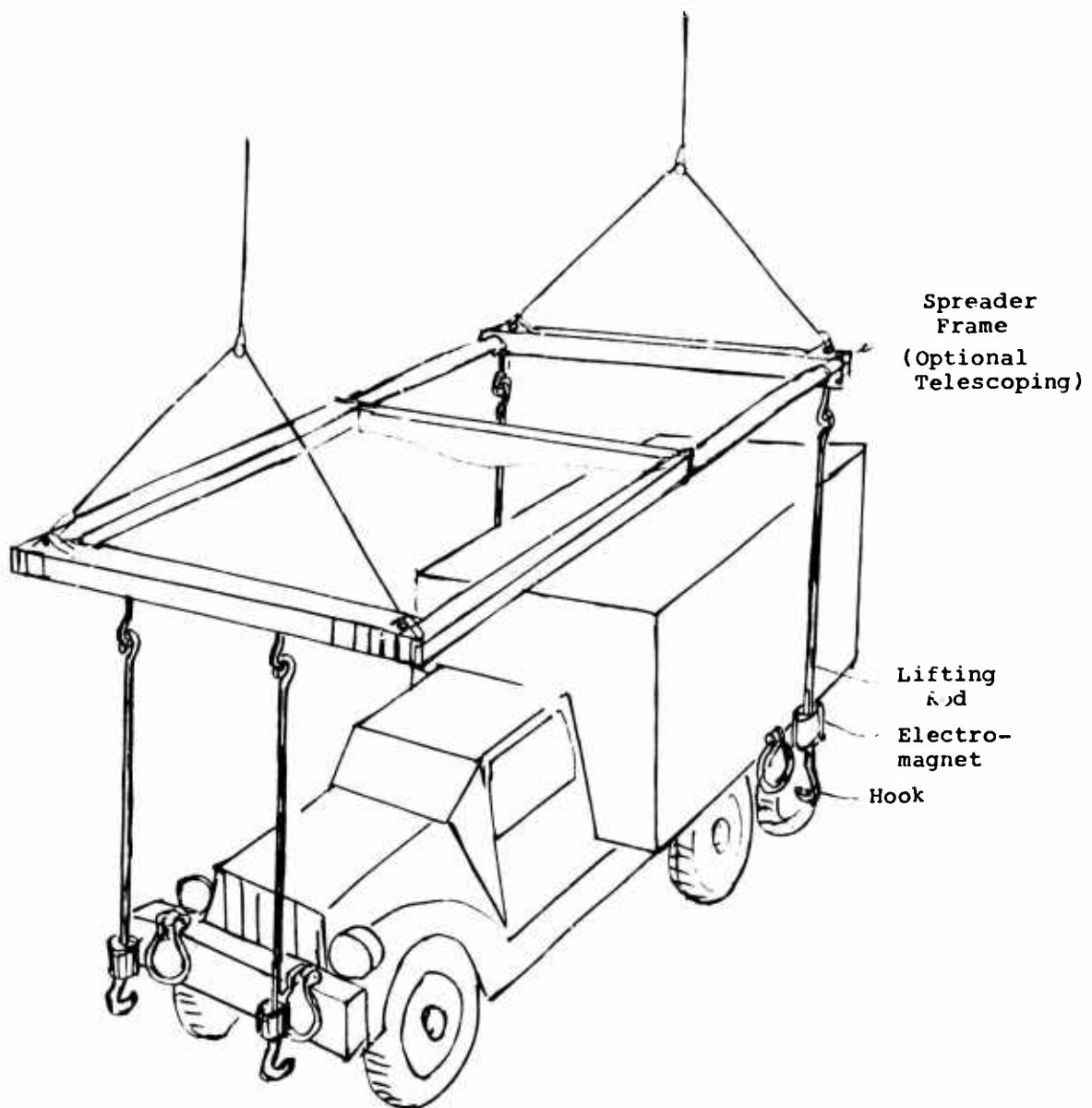


Figure 39. Application of the Magnetic Hook/Lifting Ring HALAS Concept to Automatic Acquisition of Army Trucks.

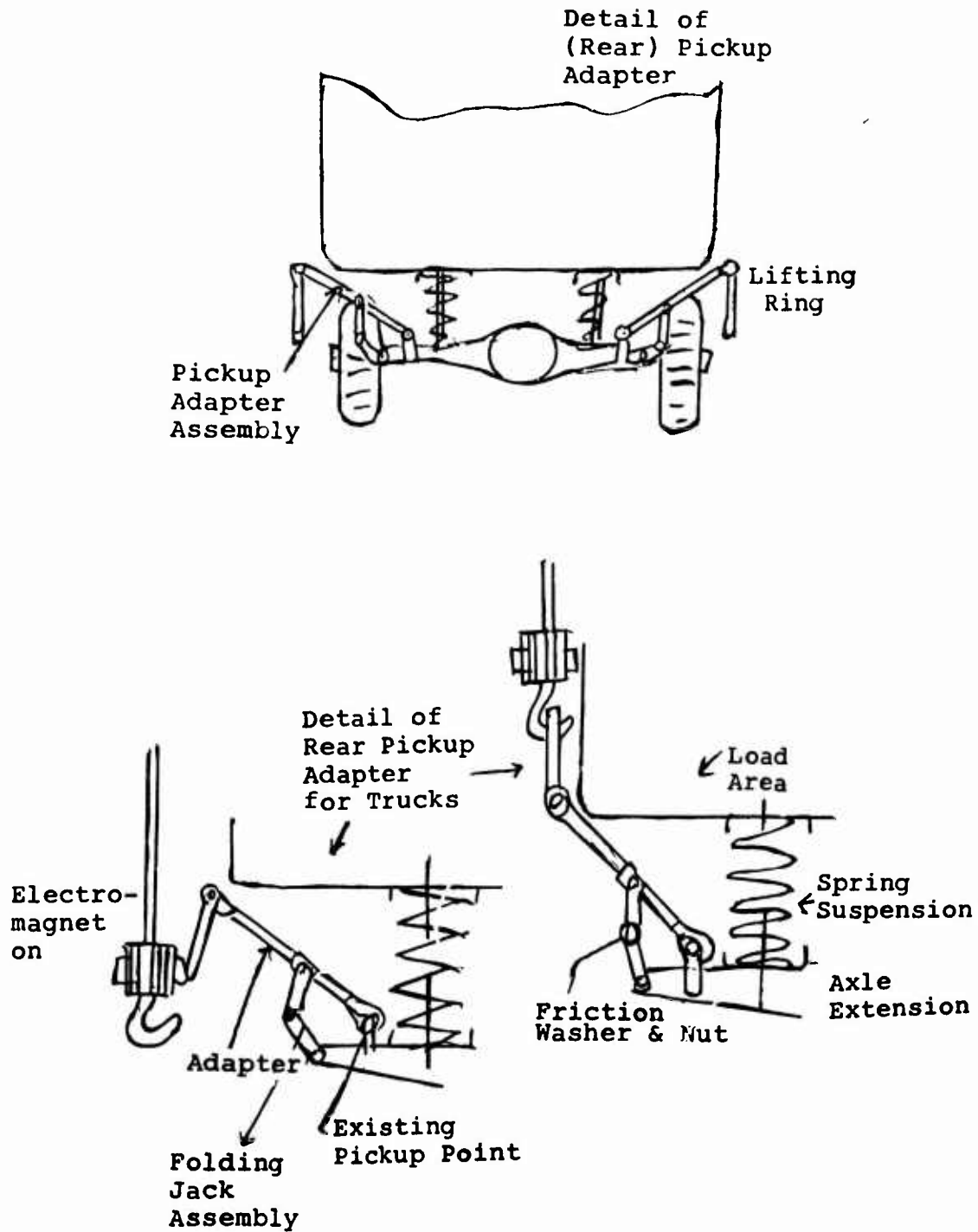


Figure 40. Design of Lifting Adapter to the Existing Lifting Provision Between Rear Drive Wheels for Typical Trucks.

pickup device, proper lifting provisions could be attached at the upper end of the lifting adapter in place of the lifting rings used for the magnetic hook/lifting ring HALAS system concept.

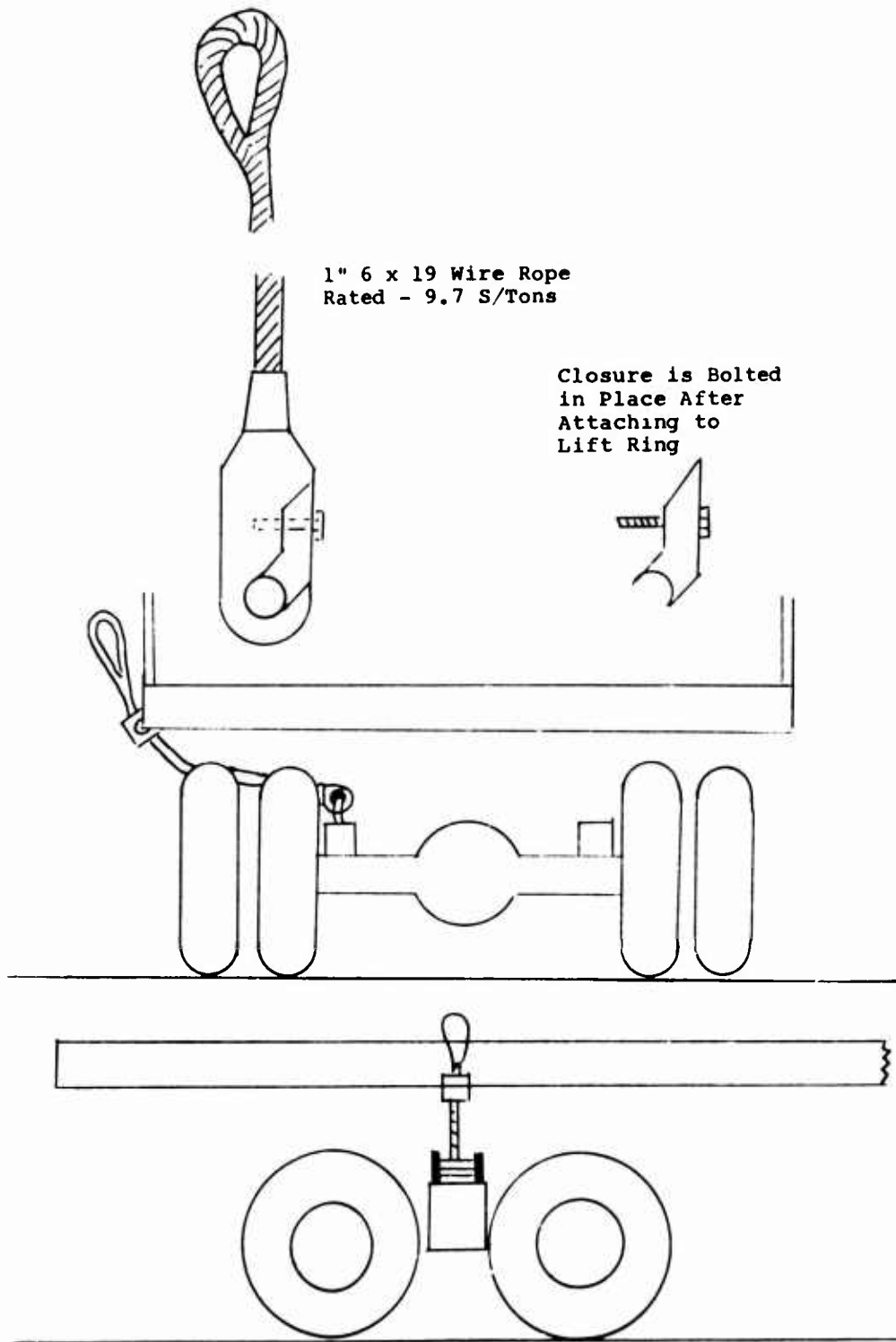
One other approach for attaching the lifting sling extension to the lifting provisions located between the drive wheels under the rear truck bed is illustrated in Figure 41. A coated wire rope sling may be used at one end of the lifting sling adapter. An adapter fitting is incorporated for attaching to the lifting provisions on the truck axle. A closure on the adapter is bolted in place after attaching to the lifting point. A corner protector can be secured on the corner of the truck bed. Such a corner protector design is illustrated in Figure 42. The sling adapter cable is free to move up and down through the corner protector guide. When lifted up by the load lifting sling, the adapter will be in tension, picking up the load at the current lifting points between the rear driving wheels of most Army trucks. By utilizing such a lifting sling adapter device, most typical Army trucks could then be automatically acquired by the various proposed HALAS systems.

#### 5.10.5 FEASIBILITY MODEL TESTING OF THE MAGNETIC HOOK HALAS CONCEPT

One of the latest concepts for automatic load acquisition has been based on magnet-aided hooks - in short, magnetic hook HALAS concept. This concept was described in Section 5.10.4, and it appears to have the advantages of the automatic load acquisition systems for both prepared and unprepared loads. A certain amount of testing has been done on a scaled model of the design concept, and the results are most encouraging. A discussion of the model, tests and results is included in the following section.

##### Feasibility Test Model

The magnetic hook HALAS concept is applicable to engagement of any type of helicopter loads. The load side of the system consists of a minor modification to the lifting provisions, which is the attachment of lifting shackles directly to the padeyes of the load. The airborne acquisition device consists of a rectangular frame with four lifting rods. The rods are equipped with magnetic hooks at their lower ends; the hooks are also of a special kind with flattened lower lip. On the lifting rods, just above the hooks, are electromagnets whose axes or directions of the magnetic force are horizontal and parallel to the plane of the hooks. In operation, the frame with the rods is lowered over the load such that the hooks are aimed roughly at the lifting eyes of the load. Once the



**Figure 41. Alternate Design Approach of Lifting Adapter to the Existing Lifting Provision Between Rear Drive Wheels for Typical Trucks.**

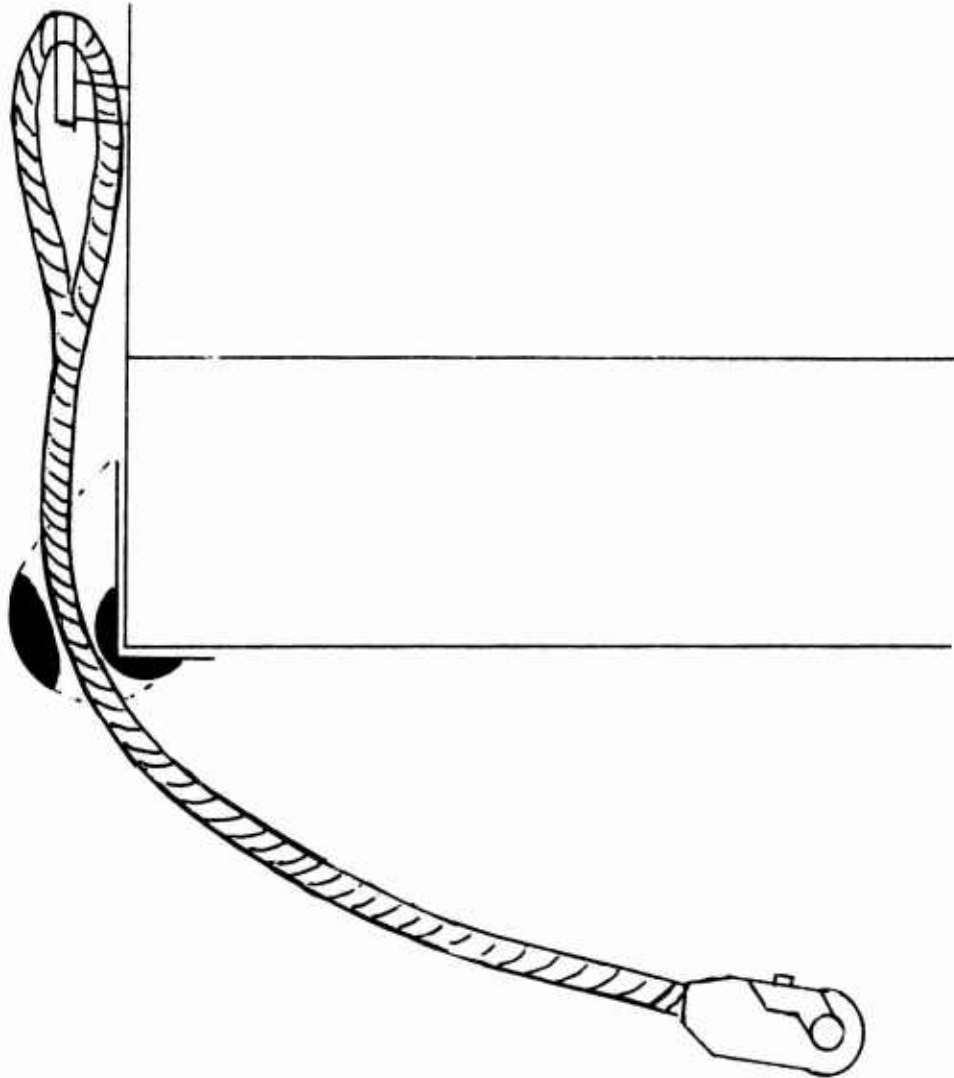


Figure 42. Corner Protector Design for Lifting Sling Adapter on Typical Trucks.

magnetic hook is in the vicinity of the attached lifting shackles on the load, the magnets then, with their magnetic attraction, perform a proximity homing function to engagement. This is the basic concept for which a scaled model has been built.

The model is made to approximately 1/12 scale. The load is simulated by a rectangular plate made of mild steel. The ferrous material is necessary to assess its effect on the magnetic homing action. The rectangular shape represents the planform of a vehicle. A better simulation of tanks is provided by bending the plate about a crosswise axis. This gives down-sloping panels similar to the fore-and-aft panels of a tank where the padeyes are located. Four brackets simulating padeyes are attached to the plate at its corners. The attached lifting shackles are simulated by ferrous rings attached to the brackets. The acquisition device consists of a fixed spreader bar type frame with short metal stubs facing down and ended with eyes for attachment of the lifting rods. The lifting rods are made to correspond approximately to 6 to 7 feet of actual length. The upper ends of the rods are formed into eyes for attachment to the stubs; the lower ends are shaped into shallow hooks. Small, permanent type magnets are attached to the rods just above the hooks. The frame is suspended by two lifting lines branching out to four corners of the frame through an intermediate, longitudinal spreader bar. When assembled and suspended by the two lines, the model of the acquisition device has the hooks, on four of the lifting rods, all aligned along the fore-and-aft axis of the device.

#### Automatic Load Acquisition Tests

In the initial set of tests, the plate simulating the vehicle was flat. The rings, simulating the lifting shackles, were then oriented all in one direction, i.e., either fore or aft on the plate. The hooks at the ends of the rods were made of double "Janus" type, or back-to-back. The acquisition device, when lowered to the plate, had the hooks aligned along the long axis of the plate. The actual engagement was effected from a slow pass of the hooks (acquisition device) toward the attached lifting shackles. In the process, the magnets would become attracted to the lifting shackles, resulting in a form of automatic homing action. The attractive force would first raise the lifting shackles off the plate; then the hook would slip under the shackle, completing the engagement.

In more recent tests, the plate simulating the vehicle was replaced by a plate bent down slightly about the middle. The lifting shackles on the sloping-down panels were made to hang downslope on both sides, making their orientation opposite for



the two pairs. The present lifting shackles represent about 6 inches in diameter. The frame with lifting rods was lowered to the plate from a direct overhead position. The engagement process consisted of hooking up the front or rear pair of lifting shackles at a time. This procedure was more exacting than the one required for the flat plate. However, it presented no detriment to the overall engagement effectiveness. Figure 43 illustrates the feasibility test model setup.

To establish some basis for assessment of the acquisition engagement performance of this concept, the acquisition phase was timed and averaged over a number of runs. For 20 approaches from a position of 2 feet (corresponding to 24 feet in actual condition) above and to the side of the plate, the engagement was completed in 15 seconds, on the average.

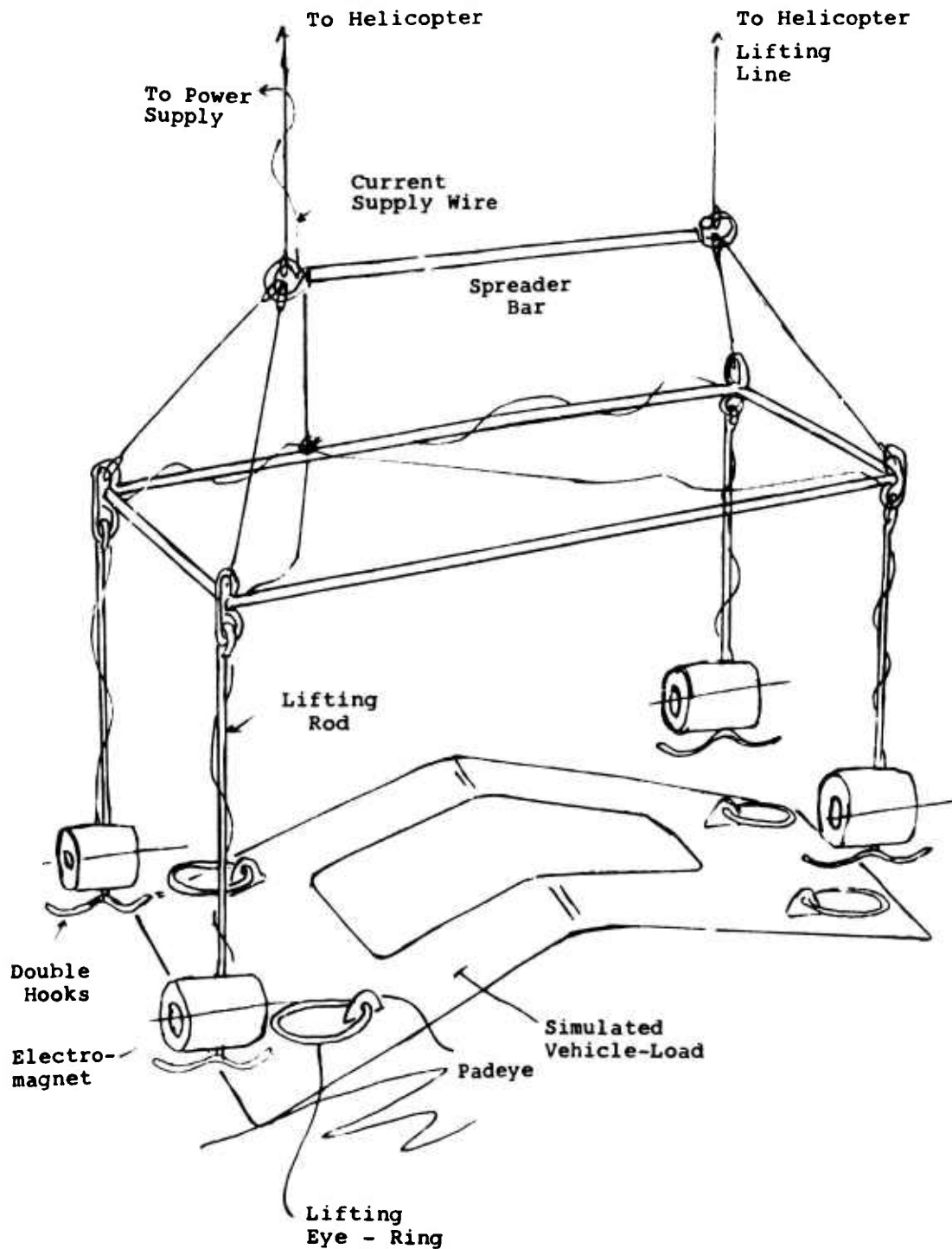


Figure 43. Magnetic Hook HALAS System Concept Feasibility Test Model.

## 6.0 DEVELOPMENT OF SYSTEM TRADE-OFF METHODOLOGY

More than 10 conceptual HALAS systems have been presented in previous sections. Methodology for assessing system effectiveness and system trade-off has to be developed to evaluate the relative merits of the conceptual HALAS concepts. The evaluation criteria must be broad enough to encompass general system considerations and detailed enough to reflect the critical areas of the actual problem. The conceptual system assessment will then be based on ascribing to the evaluation criteria an appropriate numerical level and on arriving at the point count total. A comparison of the total counts will indicate the relative effectiveness of the HALAS system.

In application to HALAS concepts, the methodology for the system assessment is described in the following. Each system consideration is allocated a number of points making up 1000 points for the maximum total. For a particular candidate HALAS system, the total grade point count can be used directly to compare the relative merits of various system design concepts. This grading system, when executed without bias, should indicate not only the relative merits of a particular design but also the degree of approach to the ideal design which would have the point count value of 1000.

Design concepts for the HALAS system are, in effect, different candidate solutions to the same problem. The system considerations to be used in the concept assessment are broad enough to fit many systems for different problems; however, when interpreted in the light of the particular problem such as HALAS, the factors serve to establish the quality profile of the concept under consideration. For a HALAS type of system, the system considerations and their maximum point values are established as follows:

- |                         |       |
|-------------------------|-------|
| 1. Simplicity of Design | (300) |
| 2. System Performance   | (250) |
| 3. Ease of Operation    | (250) |
| 4. System Versatility   | (100) |
| 5. Cost                 | (100) |

To reduce the ambiguity in the concept assessment, each factor is further identified in terms of appropriate details of the system design called areas of consideration. These areas will be affected, in turn, by general functional demands for load acquisition and engagement. Areas of consideration, which exist then within the system consideration, are

allocated shares of points commensurate with their relative importance in the factor assessment.

#### **6.1 DISCUSSION OF SYSTEM TRADE-OFF ANALYSIS**

Areas of consideration are concerned with the system design and operation for the automatic load engagement, and with some special demands on the helicopter performance, during the acquisition phase, to enable satisfactory load engagement. These areas can be grouped into:

1. Acquisition device related
2. Load related
3. Mission related
4. Helicopter related

To limit the scope of the problem, the start of the acquisition phase is here defined by:

1. The helicopter in hover over the load at a height of 50-150 feet
2. The helicopter roughly aligned with the load
3. Acquisition device (frame, etc.) approximately 25 feet above the load

Special environmental conditions, such as weather and visibility impairment, are not included at this time in this treatment. Such conditions create system requirements which are common to all design concepts advanced so far, and thus would not add any more insight to the assessment.

#### **Load Related Areas**

The load related areas have to do with some form of load preparation for acquisition which may be required by the concept. Four classes of the load status can be distinguished in this respect:

1. Unprepared load: existing lifting provisions are adequate. No preparation of the load is necessary for automatic acquisition.
2. Semi-unprepared load: existing hookup provisions are augmented by the addition of new elements. However, such additions can be left on the load permanently as a minor load modification.

3. Prepared load: new lifting elements are attached to the load and detached at destination for each airborne transport mission.
4. Semi-prepared load: new elements for lifting are added and left permanently on the load, similar to (2) above. However, these elements must be manually set prior to engagement.

#### Acquisition Device Related Areas

Acquisition device related areas have to do with the design, construction and operation of the acquisition device system. Items to consider are:

1. Design and implementation complexity
  - a. Size or shape change of the device required for each engagement operation
  - b. Remotely controlled manipulators used for engagement
  - c. Automatic homing and engagement device complexity
  - d. Functional reliability
  - e. Weight factor - device weight/load weight
2. Operational complexity
  - a. External or on-board operator
  - b. Load proximity sensor required
  - c. Remote optical viewing aids
  - d. Control and operation of the device system
  - e. Identification of hookup or engagement elements on the load
  - f. Complexity of function in hookup operation and load safetying
  - g. Acquisition phase time to engagement

## Helicopter Related Areas

The helicopter related areas have to do with:

1. Required helicopter performance accuracies in hover-hold and alignment with the load, trim and hold
2. Helicopter maneuvering for acquisition
3. Special gear or equipment in excess of standard equipment

## Mission Related Areas

The mission related areas have to do with logistics of load acquisition, i.e.:

1. Pre-mission shipment of the necessary parts, kits and men to the load site
2. Men, man-hours and equipment needed for load "dressing" and "undressing"
3. Change of the acquisition device for each load type or resetting of the same device
4. Acquisition device delivery to the depot, attachment to the helicopter and storage

## 6.2 HALAS SYSTEM ASSESSMENT MATRIX

One way of combining all the system considerations for concept assessment is to form a matrix in which appropriate combinations are provided for evaluating the point count. In the matrix, each system consideration can be evaluated in the following pattern:

Item of Consideration	SYSTEM CONSIDERATIONS				
	1	2	3	4	5
Point count assessment score by items of consideration					
Total point score for the concept					

HALAS SYSTEM ASSESSMENT MATRIX  
SYSTEM CONSIDERATIONS

	Simplicity of Design	System Performance	Ease of Operation	System Versatility	Cost	Total Count
Acquisition Device Related						400
.Design & Implementation Complexity						
.Operational Complexity						
Load Related:						300
.Unprepared						
.Semi-unprepared						
.Prepared						
.Semi-prepared						
Mission Related						200
.Pre-mission parts shipment						
.Men, Man-hours						
.Different acq. device for load type						
.Acq. device attachment, storage						
Helicopter Related						100
.Req'd perf. accuracies						
.Maneuvering						
.Load lines control						
Total Count	300	250	250	100	100	

## 7.0 SYSTEM TRADE-OFF ANALYSIS

The methodology of the system concept evaluation can be reduced to an assessment matrix.

With certain major assumptions concerning relative importance of various aspects of the system, the maximum score values have been allocated to the box item in the matrix. The assessment approach then was tried out on five selected design concepts which were described in Section 6.0. The resulting scores not only are reasonable and satisfactory but also tend to reflect on the aspects of the system design which are not directly obvious.

### The Assessment Matrix

In Section 6.0 a methodology for evaluation of the HALAS system concepts was developed. The development end result was a system assessment matrix: a tool for conducting concept evaluation, presented on the following page. Although, in the final outcome, the selection of a system concept is necessarily subjective, in which the factors playing a part in the selection are not altogether rational, it is instructive to see how such intuitive selection correlates with a more impartial assessment procedure. To make a brief review, the methodology approach taken was that for HALAS-type systems, the design concept "worthiness" can be reduced to the five factors of quality:

1. Simplicity of Design
2. System Performance
3. Ease of Operation
4. System Versatility
5. Cost

To make an assessment, each of the factors was given a score based on several considerations. These, in turn, were grouped as follows:

1. Acquisition device related
2. Load related
3. Mission related
4. Helicopter related



HALAS SYSTEM ASSESSMENT MATRIX  
SYSTEM CONSIDERATIONS

ASSESSMENT ITEMS (Max. Count)	Simplic- ity of Design (300)	System Perform- ance (250)	Ease of Operation (250)	System Versa- tility (100)	Cost (100)	Total Count (1000)
Acquisition Device Related	(150)	(100)	(90)	(30)	(30)	(400)
.Design & Im- plementation Complexity						
.Operational Complexity						
Load Related:	(90)	(80)	(80)	(30)	(20)	(300)
.Unprepared						
.Semi- unprepared						
.Prepared						
.Semi-prepared						
Mission Re- lated	(60)	(0)	(50)	(40)	(50)	(200)
.Pre-mission parts shipment						
.Men, Man-hours						
.Different acq. device for load type						
.Acq. device attachment, storage						
Helicopter Related	(0)	(70)	(30)	(0)	(0)	(100)
Req'd perf. accuracies						
.Maneuvering						
.Load lines control						
Total Count						

The assessment matrix was then formulated incorporating the system considerations and system assessment items. A maximum point count of 1000 was next allocated to the resulting boxes.

At the outset, certain assumptions were made concerning the importance of various aspects in the concept design by assigning a graduated maximum point count to each column heading and to each row heading. The maximum point scores for each system consideration and assessment item are shown in parentheses on the matrix chart. It can be seen that heavy emphasis was attached to the acquisition device related items.

#### HALAS Design Assessment

As a result of the preliminary system assessment based on the developed assessment criteria, the following five system concepts, among a dozen or so presented, were selected for further detailed system assessment analysis.

1. Forceps HALAS Concept
2. Lifting Loop Concept
3. Lifting Stud Concept
4. Magnetic Hook Concept
5. Active Arm Concept

They were selected mainly because of their higher ratings in design simplicity, ease of operation, and system versatility as compared to those of the other presented system concepts.

The results of the assessment and the relative design worthiness are shown in the assessment matrixes.

HALAS SYSTEM ASSESSMENT MATRIX  
SYSTEM CONSIDERATIONS  
FORCEPS HALAS CONCEPT

ASSESSMENT ITEMS (Max. Count)	Simplic- ity of Design (300)	System Perform- ance (250)	Ease of Operation (250)	System Versa- tility (100)	Cost (100)	Total Count (1000)
Acquisition Device Related	(150)	(100)	(90)	(30)	(30)	(400)
.Design & Im- plementation Complexity	50	20	50	5	5	130
.Operational Complexity						
Load Related:	(90)	(80)	(80)	(30)	(20)	(300)
.Unprepared						
.Semi- unprepared	90	20	40	5	20	175
.Prepared						
.Semi-prepared						
Mission Re- lated	(60)	(0)	(50)	(40)	(50)	(200)
.Pre-mission parts shipment						
.Men, Man-hours						
.Different acq. device for load type	40	0	30	5	5	80
.Acq. device attachment, storage						
Helicopter Related	(0)	(70)	(30)	(0)	(0)	(100)
.Req'd perf. accuracies						
.Maneuvering		10	10			20
.Load lines control						
Total Count	180	50	130	15	30	405

HALAS SYSTEM ASSESSMENT MATRIX  
SYSTEM CONSIDERATIONS  
ACTIVE ARM HALAS CONCEPT

ASSESSMENT ITEMS (Max. Count)	Simplic- ity of Design (300)	System Perform- ance (250)	Ease of Operation (250)	System Versa- tility (100)	Cost (100)	Total Count (1000)
Acquisition Device Related	(150)	(100)	(90)	(30)	(30)	(400)
.Design & Im- plementation Complexity	100	80	80	15	10	285
.Operational Complexity						
Load Related:	(90)	(80)	(80)	(30)	(20)	(300)
.Unprepared						
.Semi- unprepared						
.Prepared						
.Semi-prepared	20	50	50	15	10	145
Mission Re- lated	(60)	(0)	(50)	(40)	(50)	(200)
.Pre-mission parts shipment						
.Men, Man-hours	30		30	20	25	105
.Different acq. device for load type						
.Acq. device attachment, storage						
Helicopter Related	(0)	(70)	(30)	(0)	(0)	(100)
.Req'd perf. accuracies						
.Maneuvering		50	20			70
.Load lines control						
Total Count	150	180	180	50	45	605

HALAS SYSTEM ASSESSMENT MATRIX  
SYSTEM CONSIDERATIONS  
LIFTING LOOP HALAS CONCEPT

ASSESSMENT ITEMS (Max. Count)	Simplic- ity of Design (300)	System Perform- ance (250)	Ease of Operation (250)	System Versa- tility (100)	Cost (100)	Total Count (1000)
Acquisition Device Related	(150)	(100)	(90)	(30)	(30)	(400)
.Design & Im- plementation Complexity	40	60	40	20	10	170
.Operational Complexity						
Load Related:	(90)	(80)	(80)	(30)	(20)	(300)
.Unprepared						
.Semi- unprepared	90	70	60	20	10	250
.Prepared						
.Semi-prepared						
Mission Re- lated	(60)	(0)	(50)	(40)	(50)	(200)
.Pre-mission parts shipment						
.Men, Man-hours	40		40	30	30	140
.Different acq. device for load type						
.Acq. device attachment, storage						
Helicopter Related	(0)	(70)	(30)	(0)	(0)	(100)
.Req'd perf. accuracies						
.Maneuvering		40	10	0		50
.Load lines control						
Total Count	170	170	150	70	50	610

**HALAS SYSTEM ASSESSMENT MATRIX  
SYSTEM CONSIDERATIONS**

**LIFTING STUD HALAS CONCEPT**

ASSESSMENT ITEMS (Max. Count)	Simplic- ity of Design (300)	System Perform- ance (250)	Ease of Operation (250)	System Versa- tility (100)	Cost (100)	Total Count (1000)
Acquisition Device Related	(150)	(100)	(90)	(30)	(30)	(400)
.Design & Im- plementation Complexity	100	80	80	30	10	300
.Operational Complexity						
Load Related:	(90)	(80)	(80)	(30)	(20)	(300)
.Unprepared						
.Semi- unprepared	30	70	70	30	10	210
.Prepared						
.Semi-prepared						
Mission Re- lated	(60)	(0)	(50)	(40)	(50)	(200)
.Pre-mission parts shipment						
.Men, Man-hours	30		30	20	25	105
.Different acq. device for load type						
.Acq. device attachment, storage						
Helicopter Related	(0)	(70)	(30)	(0)	(0)	(100)
.Req'd perf. accuracies						
.Maneuvering		60	20			80
.Load lines control						
Total Count	160	210	200	80	45	695

HALAS SYSTEM ASSESSMENT MATRIX  
SYSTEM CONSIDERATIONS

MAGNETIC HOOK HALAS CONCEPT

ASSESSMENT ITEMS (Max. Count)	Simplic- ity of Design (300)	System Perform- ance (250)	Ease of Operation (250)	System Versa- tility (100)	Cost (100)	Total Count (1000)
Acquisition Device Related	(150)	(100)	(90)	(30)	(30)	(400)
.Design & Im- plementation Complexity	120	90	80	15	20	325
.Operational Complexity						
Load Related:	(90)	(80)	(80)	(30)	(20)	(300)
.Unprepared						
.Semi- unprepared						
.Prepared						
.Semi-prepared	70	70	70	15	20	245
Mission Re- lated	(60)	(0)	(50)	(40)	(50)	(200)
.Pre-mission parts shipment						
.Men, Man-hours	40		40	30	30	140
.Different acq. device for load type						
.Acq. device attachment, storage						
Helicopter Related	(0)	(70)	(30)	(0)	(0)	(100)
.Req'd perf. accuracies						
.Maneuvering		60	30			90
.Load lines control						
Total Count	230	220	220	60	70	800

## 8.0 CONCEPTUAL SYSTEM DESIGN

### 8.1 DESIGN OF THE MAGNETIC HOOK HALAS SYSTEM

#### Guidelines for the Design

Experimentation with the scaled model produced the following guidelines for the system design:

1. The electromagnet should be of straight core type and placed with its axis horizontal and in plane of the hook.
2. The magnet axis should be no more than 7 inches above the lower lip of the hook. One end of the iron core of the magnet should be approximately even (along the vertical) with the hook base.
3. The lifting eye must be equipped with a feature ensuring the eye separation from the metal bulk of the load (1" or 2" spacing) and another feature preventing the eye from flipping over and contacting the metal bulk. Once the eye is in contact with the metal bulk, it becomes a part of the bulk and the attracting force of the magnet is ineffective in raising the ring of the eye.
4. The main hook has to be made of nonmagnetic metal such as stainless or some alloy steels. A magnetically sensitive hook, when in contact with the metal bulk, drains the attractive force of the magnet, making the whole concept ineffective.
5. The hook must have its lower lip fairly flat for ease of slipping under the ring of the eye. The length of the lip is a compromise of several considerations. An effective engagement is enhanced with a longer hook lip preventing the ring of the eye from slipping off. However, a long lip may result in missed engagements if it spans chordwise across the ring in off-center approaches. The lip should be long enough to prevent the hook from entering inside the ring from above. This may result in a troublesome lock-in situation. The lip length extending to the center of the ring, when engaged, was found to be the best compromise. The total length of the hook, including the heel, should be slightly greater than the inside diameter of the ring.



6. An automatic latch forming a part of the hook is necessary to prevent the lifting eye from sliding off while attempts are being made to engage other hooks.

### Logistics Considerations

The size of the lifting frame has been taken, provisionally, as 5 feet by 11 feet. The telescoping action, if provided, would shorten or lengthen the frame by a few feet, probably not more than  $\pm 4$  feet. It is not clear, at this time, if the telescoping action is really necessary. The assumption, from which this need has arisen, was that the spacing of the lifting rods must be matched to the spacing of the rings on the load. Hence, different vehicles would require different rod spacings.

Experiments with the model indicate that the proper spacing is needed for the crosswise directions; mismatch of rod spacing lengthwise can be easily compensated for by the vernier maneuvering of the helicopter, which is a part of the engagement procedure. The final decision has to be left for the time of full-scale tests with a crude facsimile of the lifting device. An omission of the telescoping feature from the frame design would produce a welcome simplification.

The lifting devices would, generally, be stored at a suitable staging yard. However, the devices could be readily transported by road on a flatbed truck and delivered to a pre-assigned area for attachment. To attach the device to a cargo helicopter, the device would be laid out beside a helicopter on the ground, and the lifting lines of the helicopter would be pulled out and secured to the spreader beam of the device.

For raising the device, the helicopter would be made to lift off and traverse across to the position above the frame while keeping the lines slack. An approximately vertical rise from this position would stretch the lines and make the device airborne and ready for operation. To deposit the device, a procedure in reverse of lift-off would be applied; the device would be laid down on a flat yard while maintaining a descent with a slight traverse. At no time would it be necessary to have a man underneath the hovering helicopter to attach or detach the device or to engage the load.

Load engagement and transfer using the system of magnetically aided hooks, as described above, require the presence of lifting eyes or similar provisions on the load. Army vehicles have such provisions available. However, the size of the eyes on trucks appears to be too small for an efficient engagement,

and a replacement may be necessary. Tanks are not usually equipped with lifting eyes but only with the padeyes. Attachment of lifting eyes of proper size appears to present no problem but requires refitting of the Army vehicles either in the depot or in the field. Any other type of load may be packaged suitably into a box or a container with lifting eyes as the lifting provisions.

For a routine transfer of such loads, detachable lifting eye kits might be produced. Whatever the way, the end result must be the lifting eye type provision for the load. A fixed lifting ring should also be adequate if made of ferrous (capable of magnetic attraction) material and if a reasonable (magnetic) separation is provided from the metal body of load.

### Sizing of Mechanical Components

The basic design assumptions for the full-scale system are:

1. Nominal load factor  $w = 23 \text{ tons} = 50 \text{ kip}$
2. The vertical load factor is 2.5 limit and 4.0 ultimate.
3. The horizontal load factor is due to some dynamic flight conditions with the load and the lifting device as a compound pendulum. For a lifting device with low weight compared with the load, only the vertical load factor is of practical significance. For the design purpose, the horizontal load factor is taken equal to  $1/2$  weight.
4. During engagement, the maximum load factor on the hook is taken equal to  $1/3$  weight.
5. The lifting device should be designed in a manner similar to that for an aircraft, i.e., using high-strength/weight-ratio materials such as aluminum alloys and alloy steels.

For the preliminary design, the important stress analyses are in the following areas.

1. The frame has the sides considered as columns in compression.
2. The cradle plate for the electromagnet carries the load from the hook around the opening for the core of the magnet. Hence, the critical loading is due to bending.

3. The critical loading on the main hook is due to bending.
4. The critical loading of the latch inside the hook is due to bending.
5. The critical loading of the lifting eye is also with bending.

The sizes of the major elements as required according to the analyses have been incorporated in the design.

#### SPEC SUMMARY FOR SIZES AND WEIGHTS OF STRUCTURAL COMPONENTS

- . Frame: 24 ST Al Alloy tubes 4" x .095"  
length: 15' x 5' x 15' x 5'  
Estimated weight including lugs and  
brackets at 70 lb
- . Spreader Beam: 24 ST Al Alloy tube: 4" x .065"  
length 10'  
Estimated weight of assembly at 20 lb
- . Steel cable lines - frame to spreader: Cable 1/2" dia  
length 4" x 6'  
Estimated weight - 20 lb
- . Lifting Rods - upper tube member assembly: 24 ST Al Alloy  
2" x .065" x 55"  
Estimated weight of each - 6 lb  
Estimated weight of 4 rods 4 x 6 - 24 lb
- . Main Hook Assembly including electromagnet, cradle plate,  
etc.  
Estimated weight of each at 40 lb  
Total weight: 4 x 40 - 160 lb

Estimated total weight of the lifting device is 300 lb.

## Magnetic Hook HALAS System Configuration

The helicopter-borne lifting device is a rectangular frame with four rods attached to each corner as shown in Figure 44. The frame is made up of tubular members (aluminum alloy or alloy steel) whose basic function is to reduce the four load components from the four pickup points on the load to two load components which the two lifting lines of the helicopter are capable of carrying. Ideally, one frame would be sized to carry one particular type of the vehicle where the distances between the pickup points correspond to the spacing of the lifting rods of the device. A versatility for pickup of loads with different pickup point spacing can be achieved by making the crosswise rod spacing adjustable through a screw jack and small electric motor drive arrangement and the lengthwise rod spacing by telescoping the long sides of the frame. Screw jack and electric motor drive can also be used for that purpose. See Figures 45 and 46.

The lifting rods are metal alloy tubes capable of carrying the load under its maximum load factor without a permanent yield. They are approximately 8 feet long from the frame to the hooks. This length allows it to clear some possible vehicle superstructures such as external machine guns, etc.

The rods are suspended at the frame by means of primitive U-joints. However, one version of the device may have the U-joints replaced with ball-joints. Advantages of this are not clear at this time. See Figures 47 and 48.

The lower part of the lifting rod has engagement and homing provisions. At the low end of the rod is a hook of special design. Just above the hook is an electromagnet. It is powered from a source on board the helicopter when turned on by the load operator. The electromagnet is of the "open-ended" type with core straight and horizontal and in the plane of the hook as shown in Figure 48. Such a magnet has lines of magnetic force (magnetic flux) closing from one pole to another through the surrounding space. The magnetic field pattern is broad, and the magnetic attraction is initiated at a larger distance from the lifting eye than possible with a U-shaped magnet core seen in Figure 50.

The hook is of a special design for engagement with the lifting eye. It has the lower end flattened and extended out for several inches. The material is a magnetically neutral metal alloy such as stainless steel, etc. (Figure 49). The hook and the electromagnet are rigidly connected. They may form a separate assembly connected by a U-joint to the upper part of the lifting rod, or may be an integral part of the lifting rod. (No significant difference in operation has been found.)

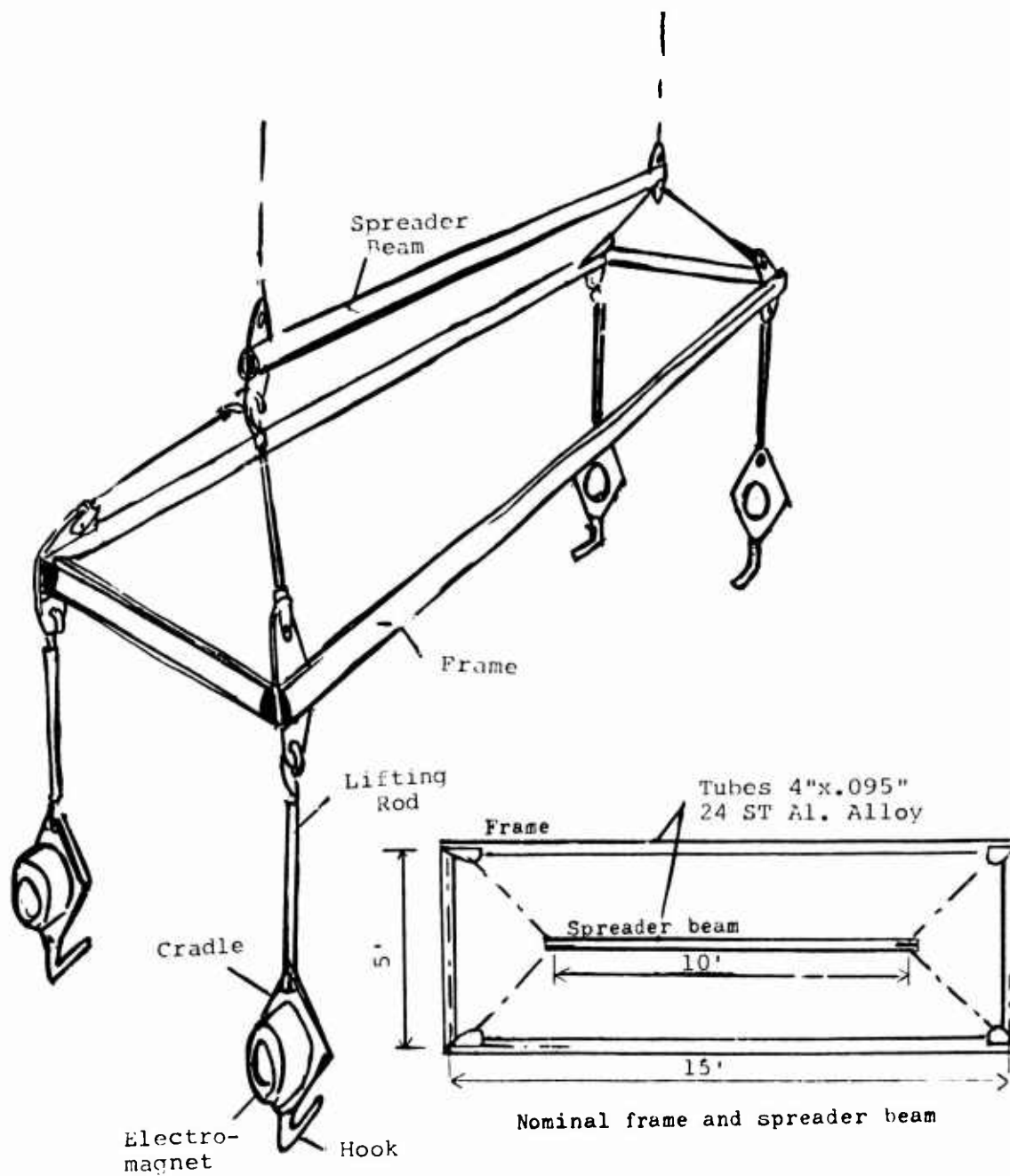


Figure 44. Lifting and Engagement Device With Magnet-Aided Hooks - Basic Layout of Components.

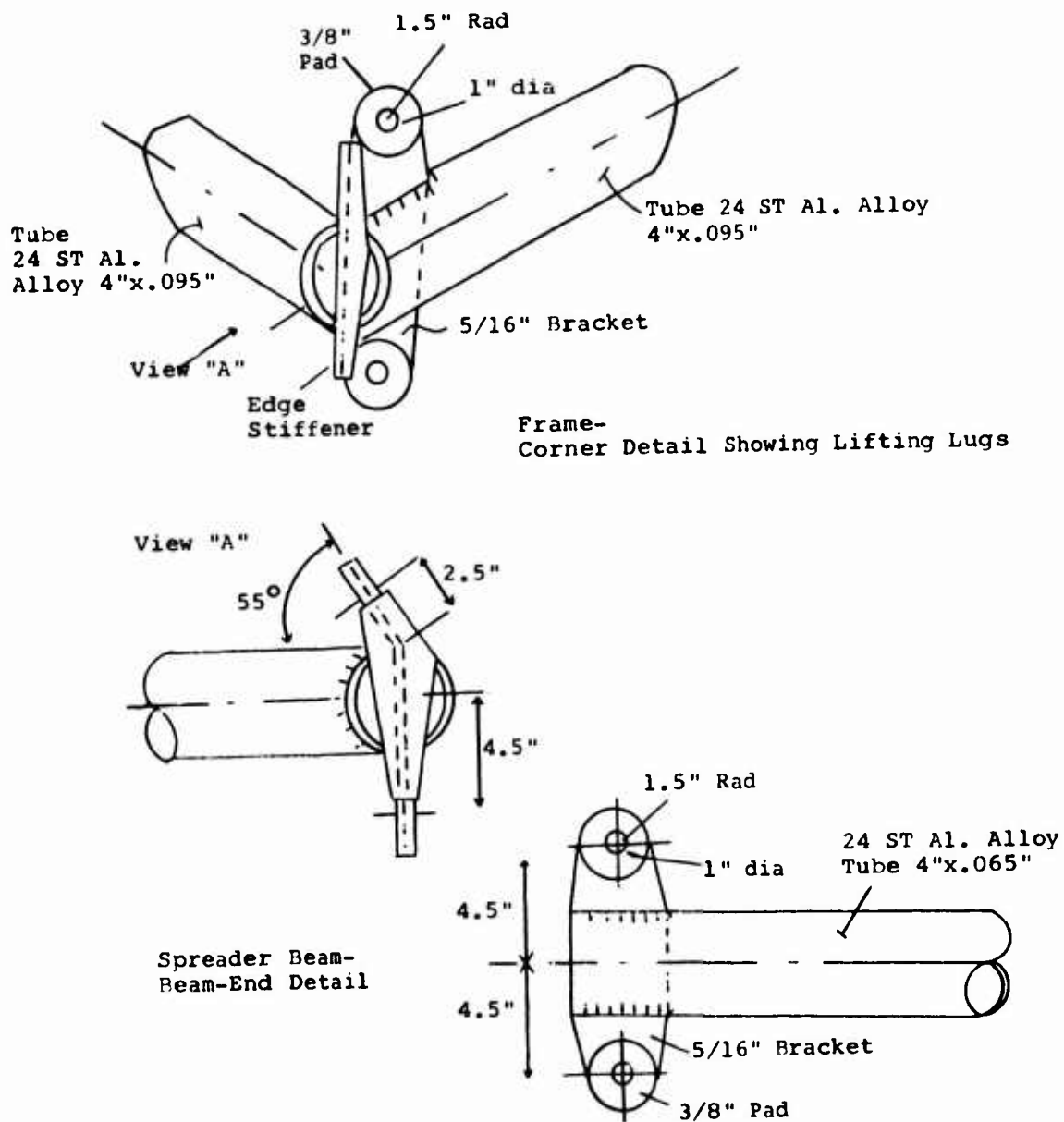
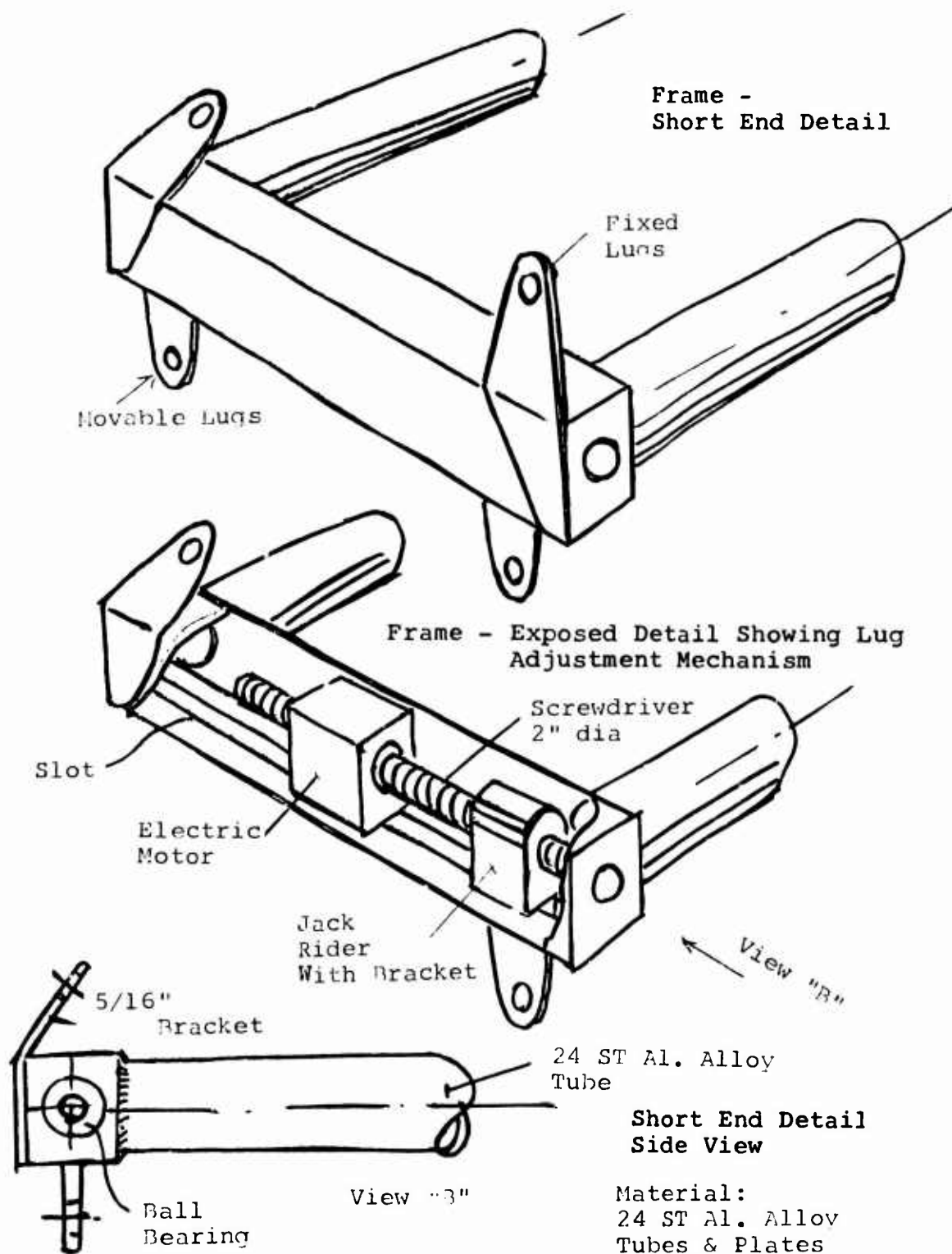


Figure 45. Sizes of Structural Elements Frame and the Spreader Beam - Nominal.



**Figure 46. Structural Details of Frame Construction Lifting Lugs Adjustable Crosswise.**

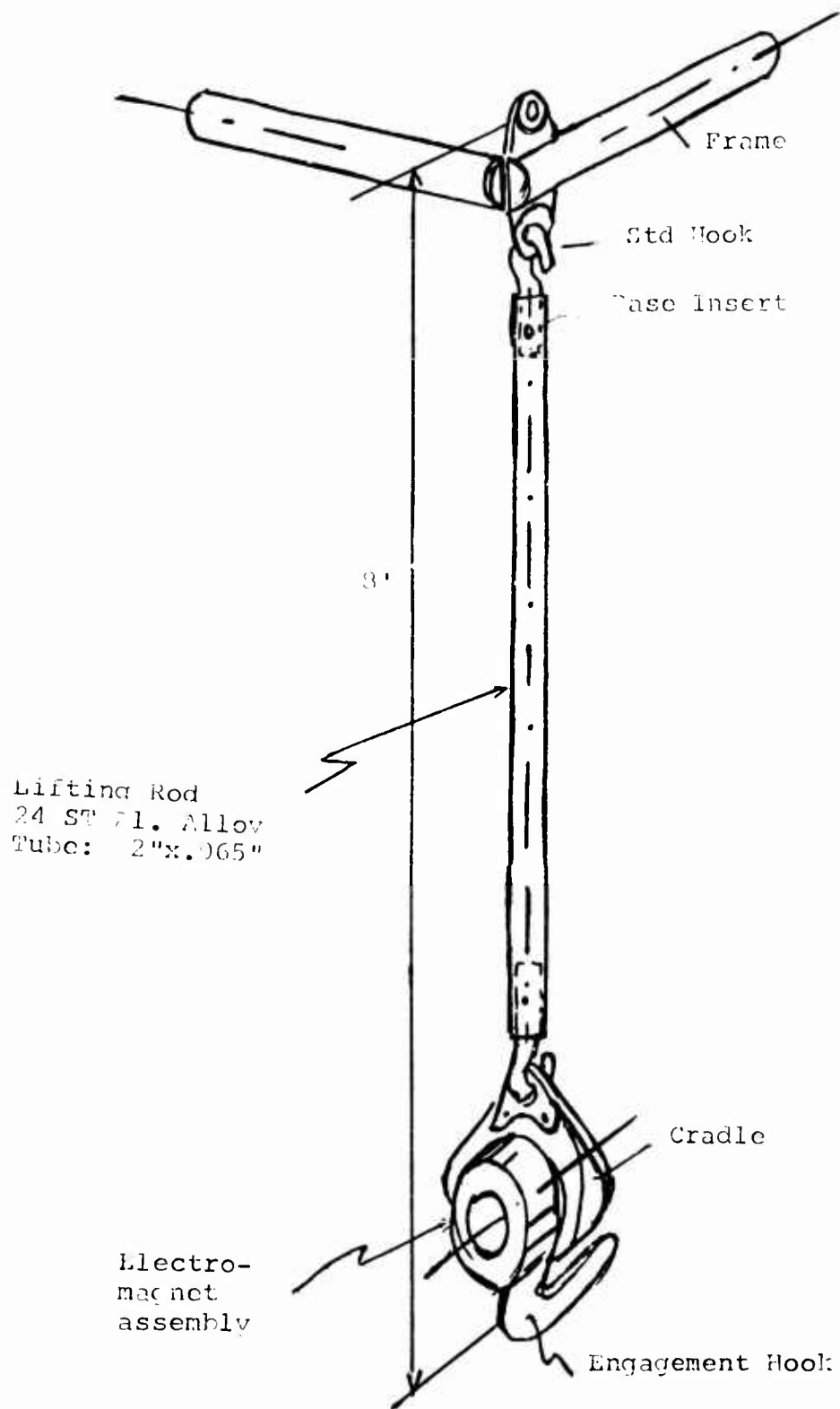


Figure 47. Lifting Rod Assembly.



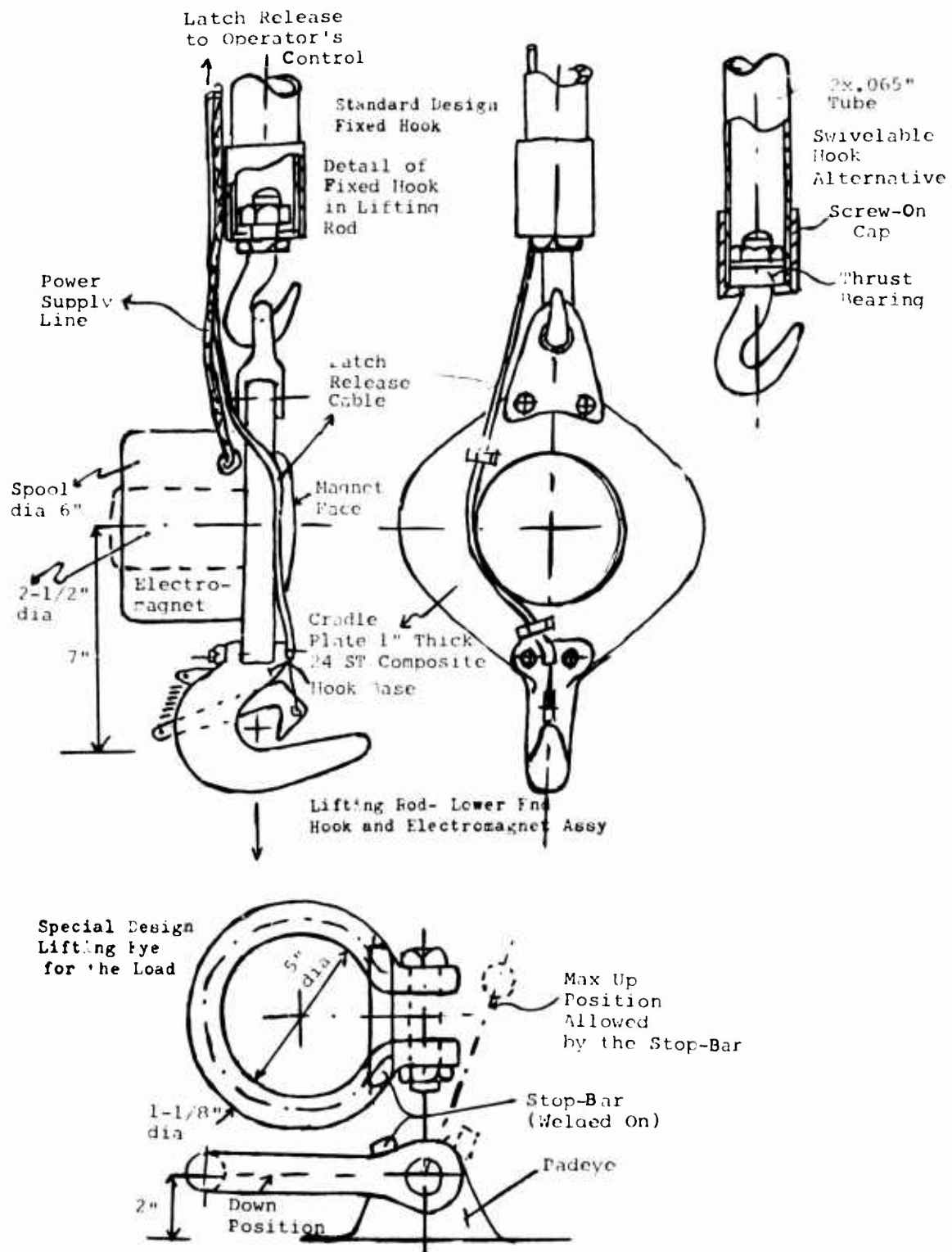
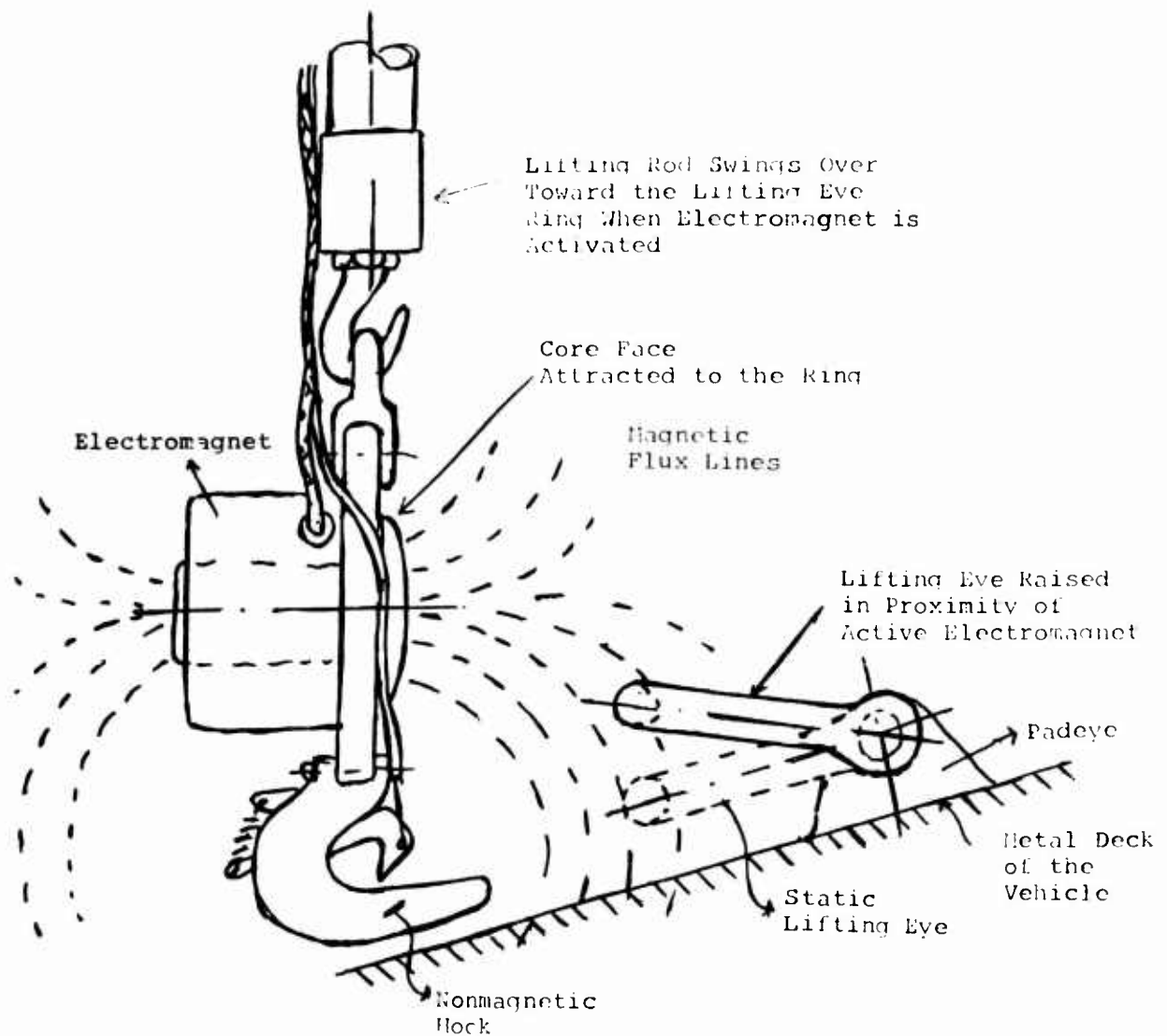


Figure 48. Design Details of Engagement Assemblies: Hook and Lifting Eye.





**Figure 50. Magnetically Aided Engagement Principle of Operation.**

The hook is equipped with a locking feature once engagement is effected. Only the release of the lock requires an energizing action by a turn-on switch at the operator's control. See Figure 48.

Before the automatic engagement system can be operated, the spacing of the rods in the lifting frame must be adjusted to the corresponding spacing of the lifting eyes on the load. Operation of the system gives the best results, i.e., the fastest engagement, when a simple sequence of activities is followed. The lifting device is brought over the load such that the bottoms of hooks are in loose contact with the body of the load. Then, the helicopter hover position is adjusted to bring the hooks to the vicinity of the lifting eyes. The location of the lifting eyes will be marked with reflective paint, and under normal good-weather and daylight conditions, visual observation for control will be sufficient.

For a quick engagement, the operator should follow the "two-and-two" procedure, where, say, two front hooks, then two rear hooks are engaged at a time. This he can do by pitching the frame slightly down-front, leaving the remaining two rear hooks high enough above the load eyes to preclude the engagement. Once the front hooks are engaged, rear-down pitching and a slight rearward shift of the helicopter position will make the rear hooks ready for engagement. The engagement uses the magnetic attraction between the magnet and the lifting eye for the terminal homing and control. Once the hook is in satisfactory proximity to the eye and the electromagnet is activated, the ring of the eye will rise up and the magnet with the rod and the hook will swing over to meet the ring. In this action the hook will be brought under the eye. Subsequent lifting up of the two hooks by either pitching up of this end of the frame or by lifting up of the whole frame will have the hooks engaged with the eyes and locked. A repetition of this action sequence with the other two hooks completes the operation.

To deposit the load at the destination, the locking features on the hooks are first released and the hooks are withdrawn from engagement by a form of back-out procedure. Again, the two-and-two procedure will give the fastest results. The hooks' locking features are released simultaneously by a single turn-on switch action.

## Sizing of Electromagnets and Power Requirements

An electromagnet is the key element of the present concept for automatic load engagement. The electromagnets are used for generation of the terminal attraction and homing of the hooks to the lifting eyes.

Based on the experiments with the system model, the general guidelines for design are:

1. The electromagnet should be of straight core type and placed with its axis horizontal and in plane of the hook.
2. The axis should be about 7 inches above the lower lip of the hook. One end of the iron core of the magnet should be approximately even with the hook base as shown in Figure 48.

Since the magnetic attraction is a fast-decaying function of the distance, it is important to have the front face of the magnet core properly forward. The position must be such that with the lifting eye in contact with the magnet core face, the hook should be just under and slightly inside the ring. Subsequent lifting of the hook should result in the desired engagement. To accommodate this condition, the design of the lower part of the lifting rod is made as shown in Figure 49. A structural cradle carrying the hook load permits the button end of the core to be placed properly.

The condition which designs the electromagnet is taken from the model. It is desirable to have some initial pull between the hook assembly and the lifting eye at a distance of 6 inches or more. It is not necessary to "keep station" to assure this. Actual random relative movement may have even larger swings. However, once the pull is experienced, the terminal homing will be exerted.

## Details of Calculations for Electromagnet

### . Data from experiments with the system model:

Electromagnet converted from a solenoid:

110 v ac, .4 amp rms

Maximum load capacity (contact force) at 1 lb

Weight of the model lifting eye at .02 lb

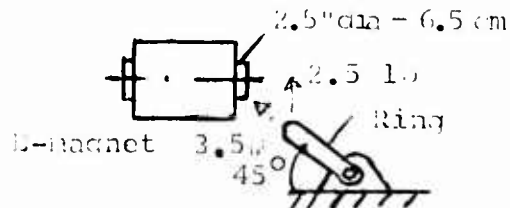
Raising of the eye initiated at about .6 in.  
from the magnet core face.

Hence, de-rated load capacity across the air gap of .6 in.  
is at .01 lb

Ratio:  $\frac{\text{De-rated force}}{\text{Contact force}} = 1\%$

Scale factor of the model 1/12 (linear dimension)

### . Full-Scale magnet size.



Lifting eye - full scale:

Inside dia = 5"

Ring thickness = 7/8" steel

Weight of half ring

$$= \frac{\pi \times 6 \times 7/8 \times .283}{2} \approx 2.5 \text{ lb}$$

Attractive (resultant)  
force at 3.5 lb

Weight of the hook assembly,  
including the cradle and  
electromagnet:

Hook	@	4 lb
Cradle		10 lb
E-Magnet		25 lb
Assy		40 lb

Pull force at 6" offset from  
vertical on the magnet assy

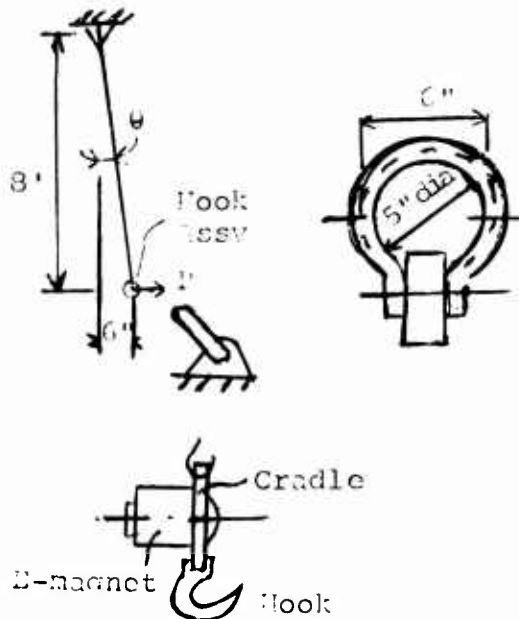
$$\theta = \frac{1}{2 \times 8} = 1/16 \text{ rad}$$

Horizontal force comp

$$P = 40/16 = 2.5 \text{ lb}$$

This is compatible with the  
force on the ring.

It is required to exert a  
pull of @ 3.5 lb at a dis-  
tance of 6" from the hook.



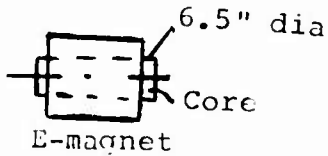
Using the analogy to the model, the "full scale" load capacity of the electromagnet is 100 x the pull at 6" distance.

Hence, the load capacity @ 100 x 3.5 lb = 350 lb.

Check of the result using electromagnet physics equations.

"Pull" force equation

$$f = B^2 A \times 10^{-7} \text{ lb}$$



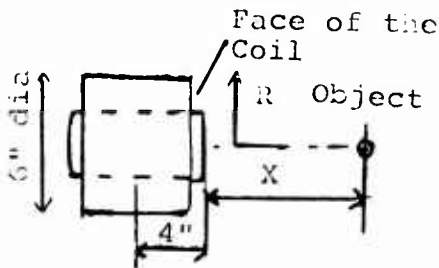
This equation is valid across a small air gap of, say, .15 cm. which can be taken as essentially contact.

B is the flux density, gauss  
A is cross section area of the core,  $\text{cm}^2$

$$\text{Hence, } A = \pi/4 \times 6.5^2 = 33 \text{ cm}^2$$

$$B^2 = \frac{350}{33} \times 10^7 = 10^8$$

Here, the force  $f = 350 \text{ lb}$ , the assumed contact load capacity of the magnet. With this an estimate of the attractive or pull force at 6" distance will be determined.



If the coil has radius R and the distance from the front face of the coil is x, the current is I and permeability  $\mu_0$

Then, the formula for the flux as a function of the distance x is

$$B = \frac{\mu_0 I R^2}{2(R^2 + x^2)^{3/2}}$$

Take the flux at the face of the coil as corresponding to the contact load, and the mean distance of the coil center to the face is 4".

$$B = B_{\text{cont}} = \frac{K}{(R^2 + 4^2)^{3/2}}$$

The rad  $R = 3"$

Then, the flux at 6" beyond the face of the coil is B'

$$\frac{B'}{B_{\text{cont}}} = \frac{(9 + 16)^{3/2}}{(9 + 100)^{3/2}} = \left(\frac{25}{109}\right)^{3/2} = .11$$

Since the pull is proportional to  $B^2$

$$\text{the ratio: } \frac{\text{Pull at 6"}}{\text{Pull at contact}} = (.11)^2 = .01 \text{ or } 1\%$$

This checks the validity of the simplified derivation using the scaled model data.

#### POWER REQUIREMENTS

Magneto-motive force at the air gap (essentially at contact)  
(air gap @ .15 cm)

$$\mathcal{E} = \frac{B}{\mu} l$$

where B is in Teslas (1T =  $10^4$  gauss)

$\mu$  is the air permeability =  $4 \times 10^{-7}$  henrys/m

l is the length of the gap =  $.15 \times 10^{-2}$  m

$\mathcal{E}$  is in amp-turns for the coil

Calculated  $B = 10^4$  gauss = 1 Tesla

$$\text{Hence, } \mathcal{E} = \frac{1 \times .15 \times 10^{-2}}{4 \times 10^{-7}} = 1000 \text{ amp-turns}$$

If the number of turns for the coil is taken 500, the current required is

$$I = 2 \text{ A dc}$$

$$\text{or } i_{\text{ac}} = 2 I = 3 \text{ amp ac}$$

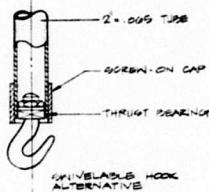
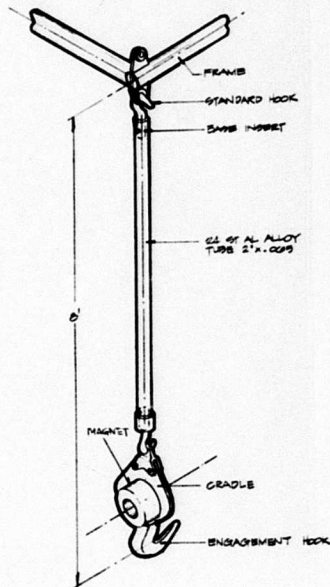
The power requirements will depend on the voltage potential of the power supply. To minimize the transmission losses, a higher voltage would be used.

Taking  $v = 110$  volts power supply  
power/one electromagnet = 350 watts

Power for all four electromagnets =  $4 \times 350 = 1.4$  kw.

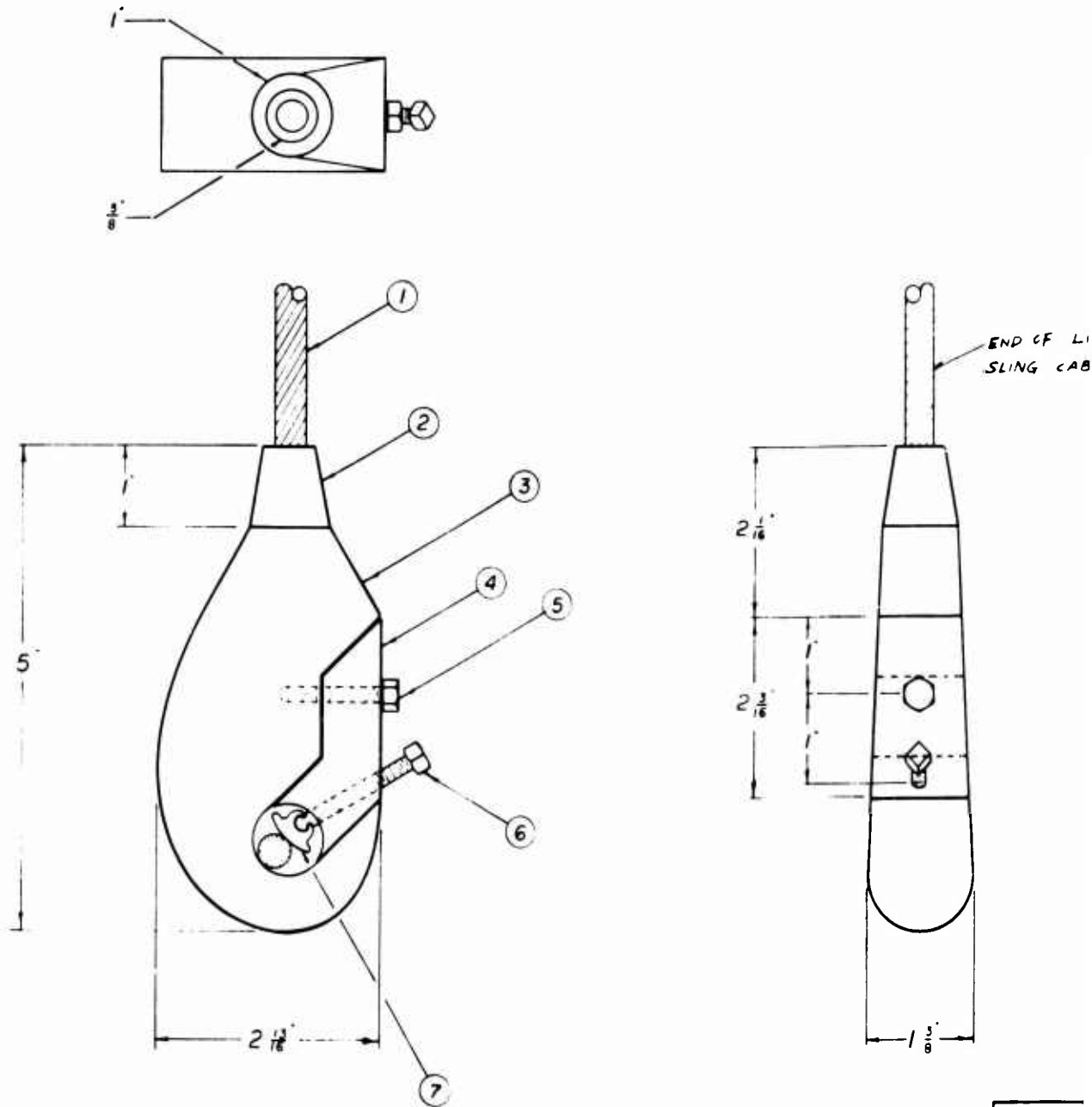


[illegible]



10						
9	JACK RIDER WITH LUG (#)					
8	ELECTRIC MOTOR (#)					
7	HOOK ASSY. (#)					
6	MAGNET (#)					
5	CRADLE (#)					
4	HOOE ROD (#)					
3	STD. HOOK (#B)					
2	FRAME ASSY. (1)					
1	SREADER BEAM ASSY. (1)					
<b>MAGNETIC HOOR HALAS DESIGN</b>						
<b>SYSTEM INNOVATION &amp; DEVELOPMENT CORP.</b>						
MO.	REVISIONS	DRAWN BY	CHECKED BY	DATE	REVISED BY	DATE
					V.L. CORRECTED BY <b>B.C.</b>	PAGE NO. <b>2 OF 4</b>
						LAYOUT NO. <b>1000</b>

8.2 UNIVERSAL LIFTING PROVISION ATTACHMENT FOR LIFTING LOOP  
HALAS

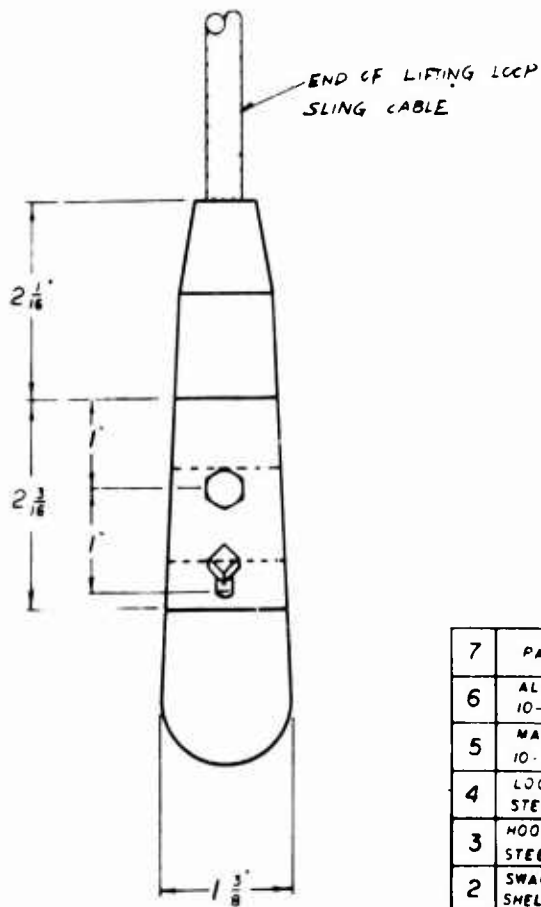
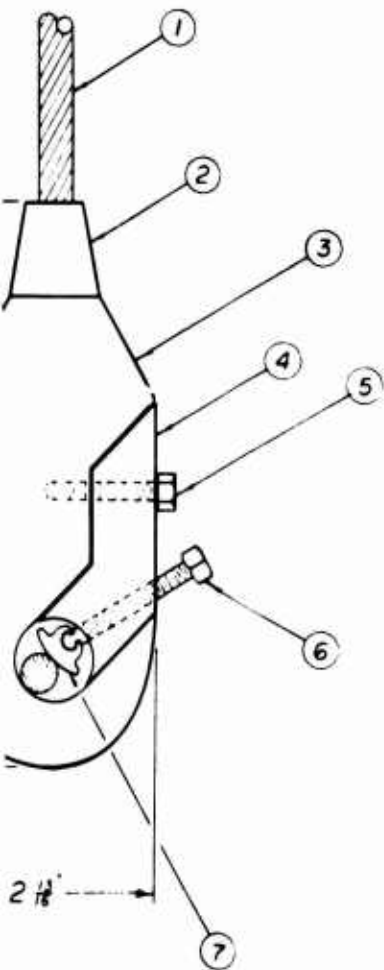
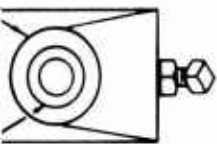


UNIVERS
FOR
SCALE 1/1
DATE 2/12/
SYSTEM
CODE IDENT

Preceding page blank

# ON ATTACHMENT FOR LIFTING LOOP

SHEET - 1



7	PAC
6	ALIGNMENT SCREW 10-24 X 1 1/2 LONG
5	MACHINE SCREW 10-24 X 1 1/2 LONG
4	LOCK PLATE STAINLESS STEEL
3	HOOK SHELL STAINLESS STEEL
2	SWAGE TERMINAL (PART OF HOOK SHELL)
1	3/8 X 7 X 7 PREFORMED SLING CABLE IN STAINLESS STEEL

UNIVERSAL LIFTING PROVISION ATTACHMENT  
FOR LIFTING LOOP HALAS DESIGN

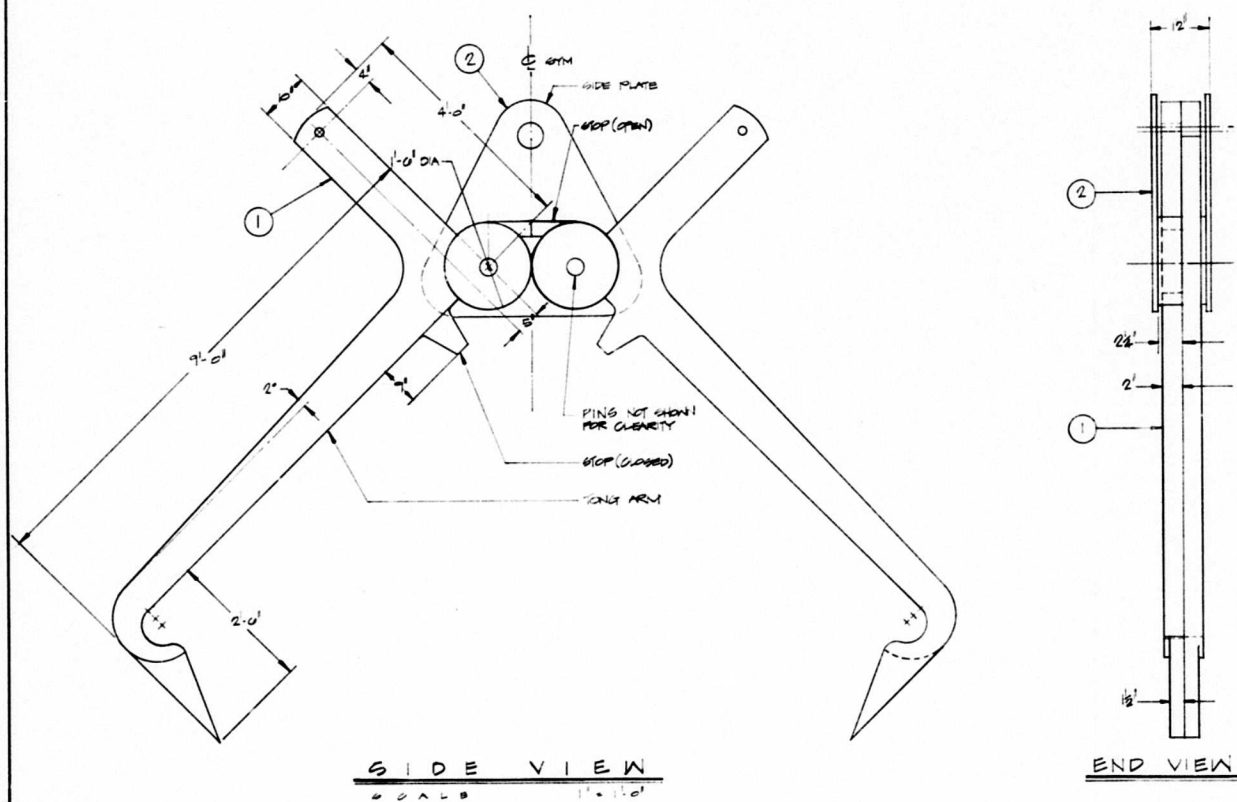
SCALE 1/1  
DATE 2/12/74  
APPROVED BY  
DI-  
DRAWN BY ML  
SIZE - C

SYSTEM INNOVATION & DEVELOPMENT CORP.

CODE IDENT NO  
DRAWING NUMBER  
2000

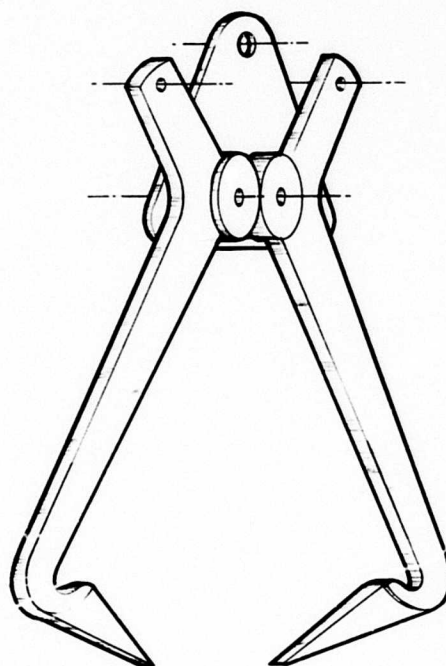
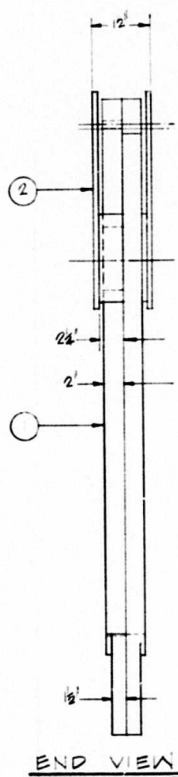
g page blank

**Preceding page blank**





# FOR LIFTING LOOP



NO.	DESCRIPTION	QTY	REMARKS
1.	ARM, TONG	2	
2.	PLATE, SIDE	2	
3.	P.N., LARGE	1	NOT SHOWN
4.	P.N., SMALL	2	NOT SHOWN
MECHANICAL TONG HOOK ACQUISITION DEVICE FOR LIFTING LOOP HALAS			
SYSTEM INNOVATION & DEVELOPMENT CORP.			
REV.	DATE	BY	APP. NO.
		M. L.	4,576
		D. W.	3001

## 153



ISOMETRIC VIEW

NO.	DESCRIPTION
1	ARM, TON OF HOOR
2	PLATE OF
3	PIN, LARGE
4	PIN, SMALL

ISOMETRIC VIEW

NO	DESCRIPTION	QTY	REMARKS
1	ARM. TONGE HOOR	2	
2	1/2" AT'S WIDE	2	
3	1/2" LARGO	1	NOT SHOWN
4	1/2" IN. DIA.	2	NOT SHOWN
5	NUTS, 1/2" X 1/2"	1	
6	ARM. CHAIR	1	
7	STRAP, MOORE HOUSING	1	

POWER, CATERPILLAR TRUCKS, AND ACQUISITION  
DEPT. FOR LISTING LOOP HALAS

SYSTEM INNOVATION & DEVELOPMENT CORP.

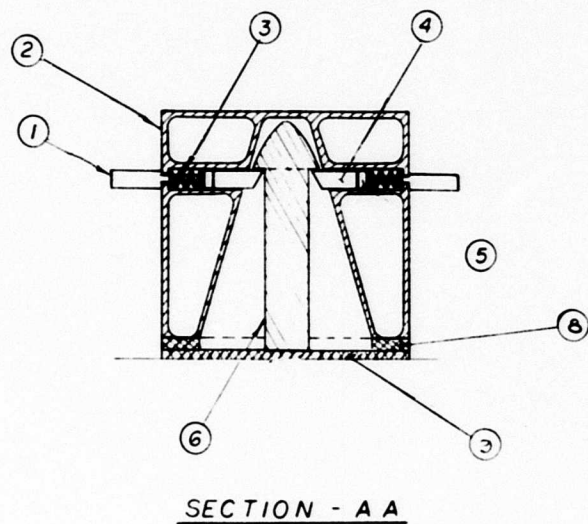
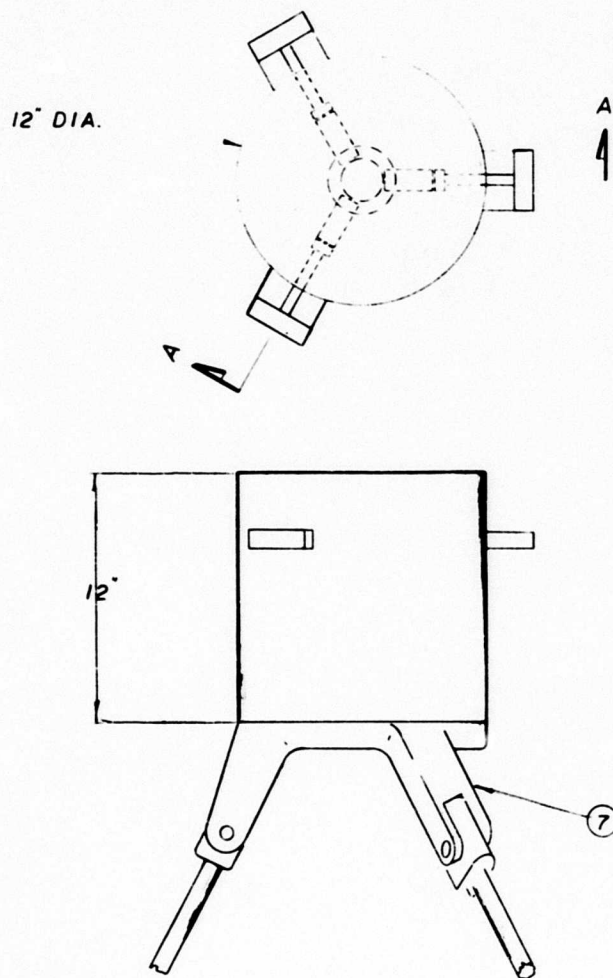
NO	DESCRIPTION	QTY	REMARKS
1	1/2" AT'S WIDE	2	
2	1/2" LARGO	1	NOT SHOWN
3	1/2" IN. DIA.	2	NOT SHOWN
4	NUTS, 1/2" X 1/2"	1	
5	ARM. CHAIR	1	
6	STRAP, MOORE HOUSING	1	

POWER, CATERPILLAR TRUCKS, AND ACQUISITION  
DEPT. FOR LISTING LOOP HALAS

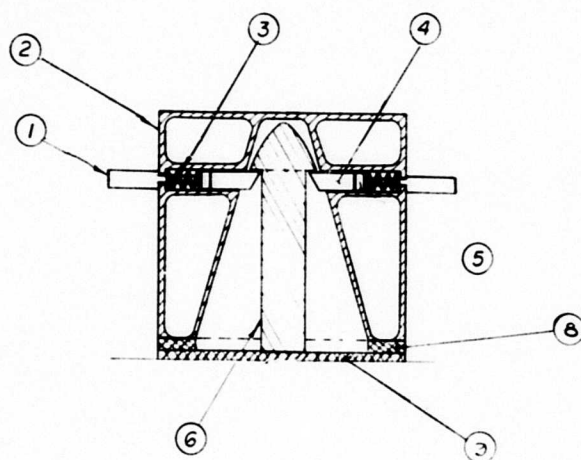
SYSTEM INNOVATION & DEVELOPMENT CORP.



## 8.4 LIFTING STUD HALAS DESIGN



A  
4



SECTION - A A

9	BASE MAGNET
8	RECEPTACLE MAGNET
7	TRI-POD ASSY.
6	MUSHROOM PIN
5	BLOCK - TYP OF (3)
4	LATCH - TYP OF (3)
3	SPRING - TYP OF (3)
2	SHELL
1	SOLENOID

LIFTING STUD HALAS DESIGN

SCALE 4/1	APPROVED BY DL	DRAWN BY ML
DATE 2/10/74		SIZE - C
SYSTEM INNOVATION & DEVELOPMENT CORP.		
CODE IDENT NO.		DRAWING NUMBER 4000

## CONCLUSIONS AND RECOMMENDATIONS

The following conclusions are drawn from the results of system analyses and design studies of HALAS concepts.

1. It is feasible to design an automatic load acquisition system for helicopter loading and unloading operation. However, further design study and testing are required to achieve a practical system design.
2. Although there exists a large variety of helicopter loads with many types of lifting provisions, one HALAS design approach could be applied to handle most of the major Army helicopter loads.
3. HALAS designs that could handle the unprepared loads, loads that do not require preparation prior to hookup, will require complex mechanization.
4. For handling prepared loads, HALAS designs are much simpler compared to those for handling the unprepared loads. However, the logistic implication in preparing the loads for loading and unloading operation should be carefully studied.
5. Standardization of the lifting provisions on all types of Army helicopter loads should be pursued. This will simplify the HALAS design and improve the efficiency in air transportation of Army loads.
6. Among the presented system concepts, lifting loop HALAS, magnetic hook HALAS, and lifting stud HALAS concepts are the most promising system approaches.
7. The feasibility of the magnetic hook HALAS concept has been proven by conceptual model testing. The reliability and efficiency need to be investigated.
8. Results of the conceptual model testing showed that the lifting loop HALAS concept is feasible. The lifting attachment to various loads is to be analyzed.
9. Magnetic homing lifting stud HALAS is another promising system concept. Further study is required to prove system feasibility and to attain practical designs.

**Preceding page blank**

**APPENDIX A**  
**ANALYSIS OF CHARACTERISTICS OF EXTERNAL**  
**LOAD TYPES AND LIFTING PROVISIONS**

Tables A-1 through A-4 present the configurations of typical Army loads and the characteristics of their lifting provisions.

As shown on the load data/lift provision tables, the lifting provisions are highly nonstandardized even for loads in the same group and category. The data also indicates that some loads have no airlifting provisions at all. The discussion on the results of the analyses of the characteristics of external load types and lifting provisions is presented in Section 3.0.

TABLE A-1. COMBAT EQUIPMENT





Index	Load Group-Type	Lin Model No.	Weight (lb)	Dimensions L-W-H (in.)	Lift Provisions - Lift Location
1	Howitzer, Light, Self-Propelled, 105-MM, M108	418420-15	40,087	240x128x114	2 Padeyes forward corners 2 Padeyes after corners 
2	Armored Recon, Airborne-Assault Vehicle - M551	A-93124	33,460	248x110x100	2 Padeyes on forward deck 2 Padeyes on after deck 
3	Carrier, Personnel, Full-Track, Armored, M113, M113A1	D-12086	23,270	191x106x100	2 Padeyes on upper forward 2 Padeyes on after upper 
4	Howitzer, Self-Propelled, Full-Track, 8" M110	K-56981	58,000	264x124x108	2 Padeyes forward corners 2 Padeyes aft on gun mount 

TABLE A-1. COMBAT EQUIPMENT









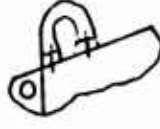



ions (in.)	Lift Provisions - Lift Locations	Present Equipment Required to Lift
8x114	<p>2 Padeyes forward corners 2 Padeyes after corners</p>  	<p>4 Double eye slings 20' long 1"x6x19 Plow Steel-fiber core (PSFC) Wire rope slings 4 Shackles 1-1/2"x1-5/8" pins</p>
0x100	<p>2 Padeyes on forward deck 2 Padeyes on after deck</p>  	<p>4 Double eye slings 15' long 3/4"x6x19 PSFC wire rope slings 4 Shackles 1"x1-1/8" pins</p>
6x100	<p>2 Padeyes on upper forward deck 2 Padeyes on after upper corners</p>  	<p>4 Double eye slings 15" long 3/4"x6x19 PSFC wire rope slings 4 Shackles 1"x1-1/8" pins</p>
4x108	<p>2 Padeyes forward corners 2 Padeyes aft on gun mount</p>  	<p>2 Double eye slings 20' long 1-1/8"x6x19 2 Double eye slings 18' long 1-1/8"x6x19 PSFC wire rope slings 4 Shackles 1-3/4"x2" pins</p>

TABLE A-1 - Continued

Index	Load Group-Type	Lin Model No.	Weight (lb)	Dimensions L-W-H (in.)	Lift Provisions - Lift Loc
5	Gun, Field Artillery, Self-Propelled, 175MM M107	J97230	62,000	451x124x108	2 Padeyes forward corners 2 Padeyes aft on gun mount 
6	Carrier, Cargo, Full-Track, 6-Ton M548	D11048	26,000	232x106x100	2 Padeyes forward corner 2 Padeyes inside aft end compartment 
7	Carrier, 107MM Mortar, Self-Propelled, M106 - M106A1	D10740	25,100	194x112x98	2 Padeyes forward upper corner 2 Padeyes after upper corner 
8	Carrier, 81MM Mortar, Full-Track, M125 - M125A1	D10725	23,800	191x106x100	2 Padeyes forward upper corner 2 Padeyes after upper corner 

Preceding page blank

TABLE A-1 - Continued









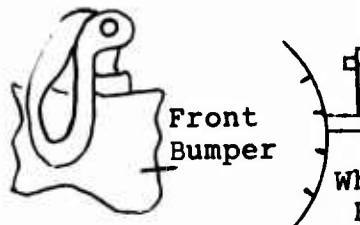
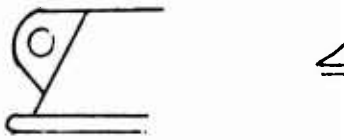
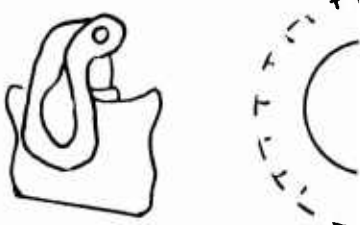
ions (in.)	Lift Provisions - Lift Locations	Present Equipment Required to Lift
4x108	<p>2 Padeyes forward corners 2 Padeyes aft on gun mount</p>  	<p>4 Double eye slings 20' long 1-1/8"x6x19 2 Double eye slings 18' long 1-1/8"x6x19 PSFC wire rope slings 4 Shackles 1-3/4"x 2" pins</p>
6x100	<p>2 Padeyes forward corner 2 Padeyes inside aft end of cargo compartment</p>  	<p>2 Double eye slings 18' long 3/4"x6x19 2 Double eye slings 20' long 3/4"x6x19 PSFC wire rope slings 4 Shackles 1"x1-1/8" pins</p>
2x98	<p>2 Padeyes forward upper corners 2 Padeyes after upper corners</p>  	<p>4 Double eye slings 15' long 3/4"x6x19 PSFC wire rope slings 4 Shackles 1"x1-1/8" pins</p>
6x100	<p>2 Padeyes forward upper corners 2 Padeyes after upper corners</p>  	<p>4 Double eye slings 15' long 3/4"x6x19 PSFC wire rope slings 4 Shackles 1"x1-1/8" pins</p>



TABLE A-2. COMBAT SERVICE

Index	Load Group-Type	Lin Model No.	Weight (lb)	Dimensions L-W-H (in.)	Lift Provisions - Lift L
101	Water Purification Eqpt Set, Truck- Mounted, Diatonite Filter 3000 gal/hr	Y36034	21,010	326x99x130	Frame extension forward Top of rear spring mount  
102	Semitrailer, Tank, Fuel, 5000-Gal., 12-Ton, 4-Dual Wheel, M131A3C	S72846	14,720	384x98x106	2 Padeyes aft of bogies tank (fwd) 2 Padeyes aft of tank ( )  
103	Truck, Van, Shop 2-1/2-Ton, 6x6, M220	X62340	15,085	267x96x130	Use of nets under all w  

Preceding page blank

TABLE A-2. COMBAT SERVICE UNITS

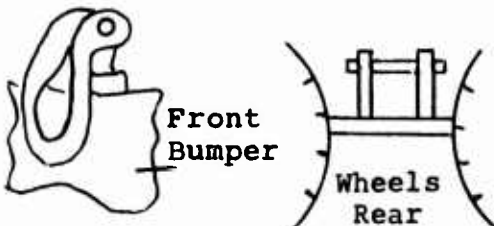

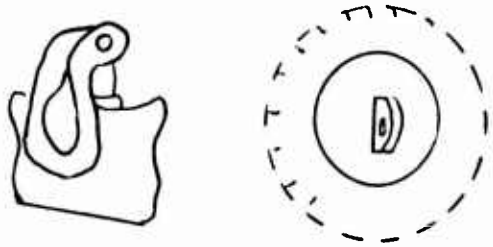


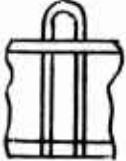

15 1.)	Lift Provisions - Lift Locations	Present Equipment Required to Lift
10	<p>Frame extension forward Top of rear spring mount</p>  <p>Front Bumper</p> <p>Wheels Rear</p>	<p>2 Spreader bars required 100" each 2 Double eye slings 20' long 3/4"x6x19 1 Double eye sling 40' long 3/4"x6x19 PSFC wire rope slings 2 Shackles 1"x1-1/8" pins</p>
16	<p>2 Padeyes aft of bogies under tank (fwd) 2 Padeyes aft of tank (aft)</p> 	<p>4 Double eye slings 20' long 3/4"x6x19 PSFC wire rope slings 4 Shackles 1"x1-1/8" pins</p>
0	<p>Use of nets under all wheels</p> 	<p>2 Spreader bars - 100" each 3 Wheel nets 48"x144" each 2 Double eye slings 20' long 3/4"x6x19 2 Double eye slings 12' long 3/4"x6x19 each with 2-DES - 6' long 3/4"x6x19 All above - PSFC wire rope slings 10 Shackles 1"x1-1/8" pins</p>

TABLE A-2 - Continued

Index	Load Group-Type	Lin Model No.	Weight (lb)	Dimensions L-W-H (in.)	Lift Provisions - Lift L
104	Semitrailer, Van, Electronic, 3-Ton, 2-Dual Wheel, M348	S74216	8,650	324x98x131	None indicated; however, wheel nets will handle w damage
105	Decontaminating Appa- ratus, Power-Driven, Truck-Mounted, 400-Gal., M9	EAM F82154	14,430	261x95x98	2 Padeyes on fwd bumper Top of rear spring mount   
106	Cooling Tower, Liquid, Semitrailer-Mounted, Badger, Model CT-1	EAM F12438	17,360	357x96x135	2 Padeyes aft of bogies 2 Padeyes fwd of rear wh   

Preceding page blank

TABLE A-2 - Continued

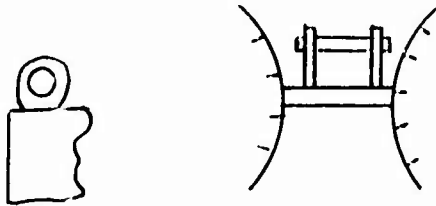




ons in.)	Lift Provisions - Lift Locations	Present Equipment Required to Lift
131	None indicated; however, use of wheel nets will handle without damage	2 Spreader bars 100" each 2 Wheel nets 48"x144" each 2 Double eye slings 20' long 3/4"x6"x19 2 Double eye slings 16' long 3/4"x6"x19 PSFC wire rope slings 4 Shackles 1"x1-1/8" pins
98	2 Padeyes on fwd bumper Top of rear spring mount  	2 Spreader bars 100" each 4 Double eye slings 20' long 3/4"x6"x19 PSFC wire rope slings 4 Shackles 1"x1-1/8" pins
135	2 Padeyes aft of bogies 2 Padeyes fwd of rear wheels  	2 Spreader bars 100" each 4 Double eye slings 20' long 3/4"x6"x19 PSFC wire rope slings 4 Shackles 1"x1-1/8" pins

TABLE A-3. TRANSPORTATION

Index	Load Group-Type	Lin Model No.	Weight (lb)	Dimensions L-W-H (in.)	Lift Provisions - Lift Location
201	Truck, Cargo, 2-1/2-Ton, 6x6, M35	X40146	13,200	278x96x112	2 Padeyes on front bumper 2 Padeyes top of rear spring mount 
202	Truck, Dump, 2-1/2-Ton, 6x6, M215	X43297	14,870	240x96x108	2 Padeyes on front bumper Wheel nets under rear 
203	Semitrailer, Stake, 6-Ton, 2-Wheel M118	S71887	7,140	275x96x106	None indicated; however, wheel nets will handle without damage
204	Truck, Cargo, 5-Ton, 6x6, M55	X41242	24,250	389x98x119	2 Padeyes on front bumper 2 Padeyes top of rear spring mount 

Preceding page blank

TABLE A-3. TRANSPORTATION EQUIPMENT

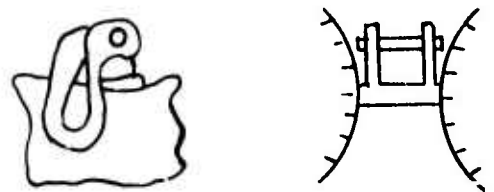
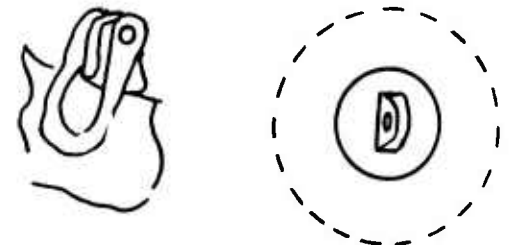
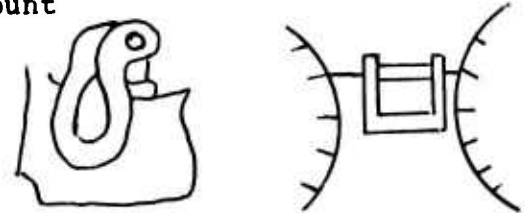

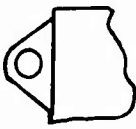
ions (in.)	Lift Provisions - Lift Locations	Present Equipment Required to Lift
x112	<p>2 Padeyes on front bumper 2 Padeyes top of rear spring mount</p> 	<p>2 Spreader Bars 100" each 4 Double eye slings 20' long 3/4"x6x19 PSFC wire rope slings 4 Shackles 1"x1-1/8" pins</p>
x108	<p>2 Padeyes on front bumper Wheel nets under rear wheels</p> 	<p>4 Double eye slings 16' long 3/4"x6x19 PSFC wire rope slings 2 Wheel nets 48"x144" 6 Shackles 1"x1-1/8" pins</p>
x106	<p>None indicated; however, use of wheel nets will handle without damage</p>	<p>2 Spreader bars 100" each 4 Double eye slings 16' long 6x19 PSFC 2 Wheel nets 48"x144" 4 Shackles 1"x1-1/8" pins</p>
x119	<p>2 Padeyes on front bumper 2 Padeyes top of rear spring mount</p> 	<p>2 Spreader bars 100" each 2 Double eye slings 20' long 6x19 PSFC 2 Double eye slings 24' long 6x19 PSFC 4 Shackles 1"x1-1/8" pins</p>

TABLE A-3 - Continued

Index	Load Group-Type	Lin Model No.	Weight (lb)	Dimensions L-W-H (in.)	Lift Provisions - Lift L
205	Truck, Tractor, 10-Ton, 6x6, M123	X59600	28,940	289x114x93	2 Padeyes on front bumper 2 Padeyes top of rear sp  
206	Semitrailer, Van, Cargo, 12-Ton, 4-Wheel, M128A1C	S74079	15,450	353x96x142	None indicated; however, wheel nets will handle w damage
207	Semitrailer, Stake, 12-Ton, 4-Wheel, M127A1C	S72024	13,980	351x98x108	2 Padeyes fwd edge of be 2 Padeyes aft edge of be suggest same gear as S  
208	Semitrailer, Low-Bed Wrecker, 12-Ton, 4-Wheel, M270	S70243	17,590	596x97x121	None indicated suggest same as S74079

Preceding page blank

TABLE A-3 - Continued


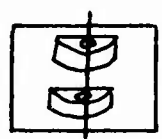




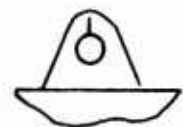





ons in.)	Lift Provisions - Lift Locations	Present Equipment Required to Lift
x93	<p>2 Padeyes on front bumper 2 Padeyes top of rear spring</p>  	<p>4 Double eye slings 20' long 6x19 PSFC 4 Shackles 1"x1-1/8" pins</p>
142	<p>None indicated; however, use of wheel nets will handle without damage</p>	<p>2 Spreader bars 100" each 2 Double eye slings 20' 3/4"x6x19-PSFC 2 Double eye slings 16' 3/4"x6x19-PSFC 3 Wheel nets 48"x144" 6 Shackles 1"x1-1/8" pins</p>
108	<p>2 Padeyes fwd edge of bed 2 Padeyes aft edge of bed suggest same gear as S74079</p>  	<p>2 Spreader bars 100" each 4 Double eye slings 30' 6x19 - PSFC 4 Shackles 1"x1-1/8" pins</p>
121	<p>None indicated suggest same as S74079</p>	<p>2 Spreader bars 100" each 2 Double eye slings 20' 3/4"x6x19 2 Double eye slings 16' 3/4"x6x19 3 Wheel nets 48"x144" 6 Shackles 1"x1-1/8" pins</p>







TABLE A-4. CONSTRUCTION

Ref.	Load Group-Type	Lin Model No.	Weight (lb)	Dimensions L-W-H (in.)	Lift Provisions - Lift L
401	Crane, Wheel-Mounted, 20-Ton, 3/4-Yd, 2-Engine, Diesel-Driven, 4x4, Rough-Terrain	F39378	56,530	522x128x154	2 Padeyes on frame over wheels 2 Padeyes on frame aft c wheels  
402	Crane-Shovel, Basic Unit, Truck-Mounted, 20-Ton, 3/4-Yd, Garwood Model M-20-A	FSN 3810-527-8613	56,100	341x108x148	2 Padeyes on frame aft c 2 Padeyes on top of gant  
403	Scraper, Earth-Moving, Towed, 18-Cu Yd Scoop, Curtiss-Wright Mod CWT-18M	S56804	39,400	487x124x128	1 Padeye top front of yo 2 Padeyes mid-unit at jo 2 Padeyes on top front o wheels  
404	Conveyor, Belt, Pneu Tires, Elec-Driven, 52' Long, 300 Tons per Hr, Barber-Greene Mod PG70	EAM FOG6424	9,420	682x120x143	2 Padeyes at base of whe 2 Padeyes midway between and base  

Preceding page blank

TABLE A-4. CONSTRUCTION EQUIPMENT

ons in.)	Lift Provisions - Lift Locations	Present Equipment Required to Lift
xl54	<p>2 Padeyes on frame over front wheels</p> <p>2 Padeyes on frame aft of rear wheels</p> 	<p>4 Double eye slings 20' long 1-1/8"x6x19 PSFC wire rope slings</p> <p>4 Shackles 1-1/2"x1-5/8" pins</p>
xl48	<p>2 Padeyes on frame aft of cab</p> <p>2 Padeyes on top of gantry</p> 	<p>2 Double eye slings 16' long 1-1/8"x6x19</p> <p>2 Double eye slings 24' long 1-1/8"x6x19 PSFC wire rope slings</p> <p>4 Shackles 1-1/2"x1-5/8" pins</p>
xl28	<p>1 Padeye top front of yoke</p> <p>2 Padeyes mid-unit at joint</p> <p>2 Padeyes on top front or rear wheels</p> 	<p>5 Double eye slings 20' long 1-1/8"x6x19 PSFC wire rope slings</p> <p>5 Shackles 1-1/2"x1-5/8" pins</p>
xl43	<p>2 Padeyes at base of wheels</p> <p>2 Padeyes midway between wheels and base</p> 	<p>2 Double eye slings 12' long 3/4"x6x19</p> <p>2 Double eye slings 10' long 3/4"x6x19 PSFC wire rope slings</p> <p>4 Shackles 1"x1-1/8" pins</p>

APPENDIX B  
DEVELOPMENT OF METHODOLOGY FOR ANALYZING HALAS  
SYSTEM PERFORMANCE AND REQUIREMENTS

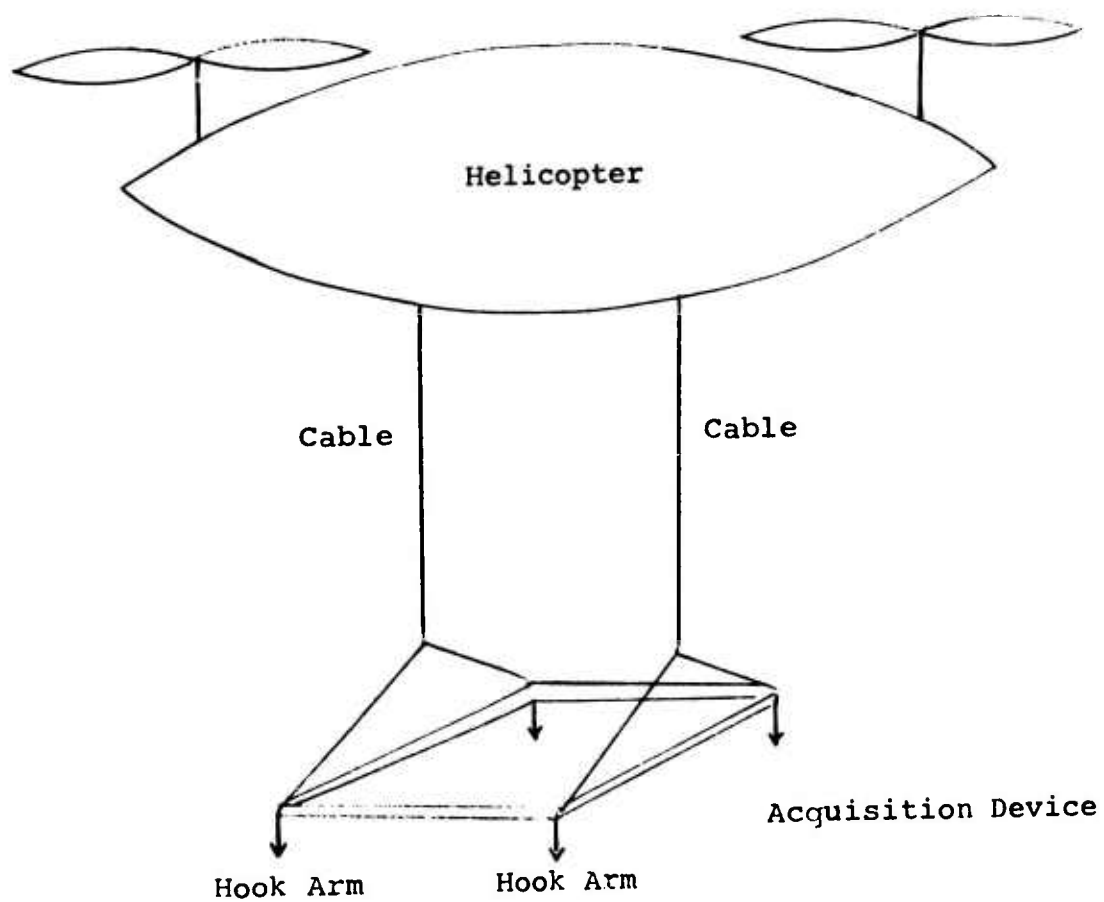
In order to configure an effective automated load acquisition system, it is necessary to determine the dispersion of the acquisition device in relation to the lifting provisions of the load. In the generalized load acquisition situation, the acquisition device would normally be attached to a lifting frame which in turn is attached to the helicopter by sling cable. The dispersion of the acquisition device in relation to the lifting provisions of the load was analyzed for a hovering helicopter under gusty conditions. Pilot response in the loop was also incorporated in the analysis. The results of the analysis were used to provide design guidance, and to evaluate the system feasibility.

Figure B-1 shows a helicopter with two cables suspended from it carrying an "intermediary body" which in turn has hooks that will fit into catches on the load. In order to determine whether these hooks can be put into the catches, it is necessary to determine the response of the helicopter and intermediary body to gust loads and stick inputs.

$H_1$  and  $H_2$  are the suspension points on the helicopter from which two cables are run to points  $R_1$  and  $R_2$  on the intermediary body. From the geometry of the problem, the helicopter and intermediary body will have the same pitch attitude,  $\theta$ , and both cables make the same angle  $\lambda$  with the vertical.

The general procedure is to use Lagrange's equations. In so doing, it is necessary to express the kinetic and potential energy of the whole system shown in Figure B-2, which is the dynamic system model.

Preceding page blank



**Figure B-1.** Configuration of Helicopter With Load Acquisition System.

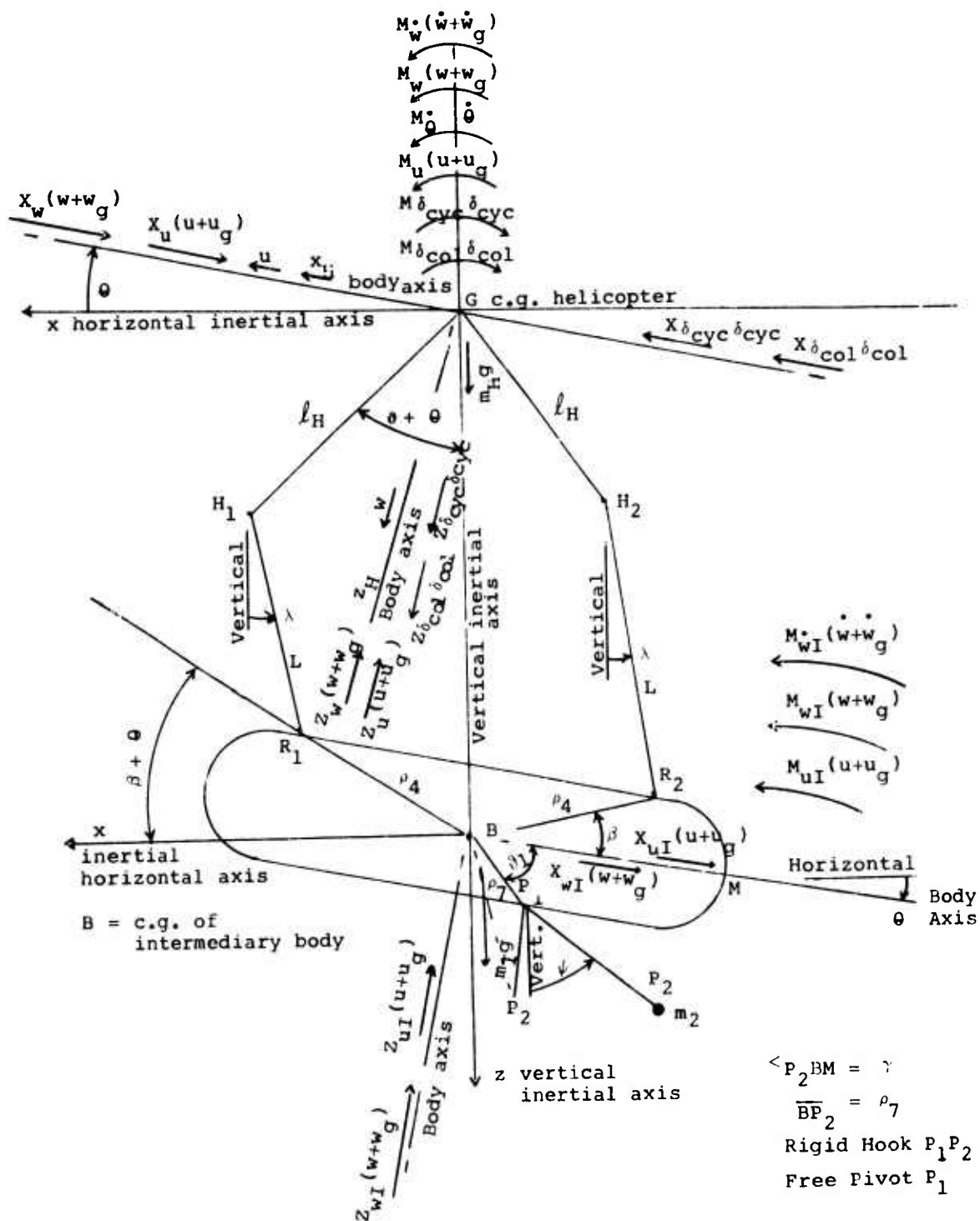


Figure B-2. Dynamic System Model.

The kinetic energy of the system is as follows:

$$T = \left[ \begin{aligned} & \frac{1}{2}I_H(\dot{\theta})^2 + \frac{1}{2}m_H u^2 + \frac{1}{2}m_H w^2 + \frac{1}{2}I_I(\dot{\theta})^2 + \frac{1}{2}m_I u^2 + \frac{1}{2}m_I w^2 \\ & + \frac{1}{2}m_I L^2(\dot{\lambda})^2 + \frac{1}{2}m_I \ell_H^2 \cos^2 \vartheta (\dot{\theta})^2 - m_I L u \dot{\lambda} \cos(\theta + \lambda) \\ & + m_I \ell_H \cos \vartheta u \dot{\theta} - m_I L w \dot{\lambda} \sin(\theta + \lambda) - m_I L \ell_H \cos \vartheta \dot{\lambda} \ddot{\theta} \cos(\theta + \lambda) \\ & + \frac{1}{2}m_I(\dot{\theta})^2(\ell_H^2 \sin^2 \vartheta + \rho_4^2) - m_I \ell_H (\sin \vartheta) w \dot{\theta} \\ & - m_I \ell_H \rho_4 \sin \vartheta \cos \beta \cos^2 \theta (\dot{\theta})^2 + m_I \rho_4 \cos^2 \theta (\sin \beta) u \dot{\theta} \\ & + m_I \rho_4 \cos \beta \cos^2 \theta w \dot{\theta} - m_I L \rho_4 \sin \beta \cos \lambda (\cos \theta) \dot{\lambda} \ddot{\theta} \\ & + m_I \ell_H \rho_4 \cos \vartheta \sin \beta \cos^2 \theta (\dot{\theta})^2 \end{aligned} \right]$$

The potential energy of the system comes out as

$$\begin{aligned} V = & g(m_H + m_I) \int \sin \theta \, dx_H - g(m_H + m_I) \int \cos \theta \, dz_H \\ & + m_I g(L - L \cos \lambda) + m_I g(\ell_H \cos \vartheta - \ell_H \cos \vartheta \cos \theta) \\ & + m_I g \ell_H \sin \vartheta \int \cos \theta \, d\theta - m_I g \rho_4 \cos \beta \int \cos \theta \, d\theta \\ & + m_I g \rho_4 \sin \beta \int \sin \theta \, d\theta \end{aligned}$$

The Lagrangian function is then computed from

$$L' = T - V$$

where we have used the prime because  $L$  was used for a length.

It is now necessary to use

$$\frac{d}{dt} \left( \frac{\partial L'}{\partial \dot{q}_i} \right) - \frac{\partial L'}{\partial q_i} = Q_i$$

where  $q_i$  = generalized displacement

$\dot{q}_i$  = generalized velocity

$Q_i$  = generalized force, not including conservative forces (gravity).

The generalized forces are identified from the summing of products of external forces (or moments) and virtual displacements at point of application of force; therefore, this is virtual work. These virtual displacements are put in terms of virtual generalized displacements.

#### Dynamic Response of Helicopter, Intermediary Body, and Free-Floating Acquisition Hook to Gusts and Load-Control Crewman Inputs

The derivations presented in the previous section are extended for analyzing a HALAS system for free-floating hook in response to gusts and pilot inputs. Figures B-1 and B-2 show a helicopter with two sling cables suspended from it, carrying an "intermediary body", load acquisition frame, which has a free-floating hook that will engage the lifting provisions on the load.

From the geometry of the problem, the helicopter and intermediary body will have the same pitch attitude,  $\theta$ , and both sling cables make the same angle  $\lambda$  with the vertical. Hook  $P_1P_2$  is free-floating with a mass  $m_2$  at point  $P_2$ .  $\psi$  is the angle that  $P_1P_2$  makes with the vertical.  $m_{12}$  is the mass of the hook exclusive of mass  $m_2$ .  $I_{12}$  is the inertia of hook  $P_1P_2$  exclusive of  $m_2$ . Letting  $P_3$  be the c.g. of hook  $P_1P_2$  (exclusive of  $m_2$ ), then  $\rho_9$  is distance  $P_1P_3$ . Also let  $\rho_6$  be distance  $P_1P_2$ .

The extended dynamic equations are presented on the following page.

$$\begin{bmatrix}
 (s(m) + X_u + X_{uI}) & (X_w + X_{wI}) & \begin{bmatrix} m_I l_H \cos \vartheta \\ s^2 \begin{bmatrix} +m_{122} d_1 \\ +m_I \rho_4 \sin \beta \end{bmatrix} \\ +gm \end{bmatrix} & \begin{bmatrix} s^2(-m_{-H} L) \\ s^2(-\pi_1) \end{bmatrix} & \begin{bmatrix} u(s) \\ w(s) \\ \theta(s) \\ \lambda(s) \\ \psi(s) \end{bmatrix} \\
 (Z_u + Z_{uI}) & \begin{bmatrix} s(m) \\ +Z_w + Z_{wI} \end{bmatrix} & (s^2 m_{122} \rho_5 \cos \vartheta_1) & - & \\
 \begin{bmatrix} M_u + M_{uI} \\ +X_{uI} l_H \cos \vartheta \\ +X_{uI} \rho_4 \sin \beta \\ +s(m_I l_H \cos \vartheta) \\ +s(m_{122} d_1) \\ +s(m_I \rho_4 \sin \beta) \\ + \frac{mg}{s} \end{bmatrix} & \begin{bmatrix} M_w + M_w s \\ +M_{wI} + M_{wI} s \\ +X_{wI} l_H \cos \vartheta \\ +X_{wI} \rho_4 \sin \beta \\ +s(m_{122} \rho_5 \cos \vartheta_1) \end{bmatrix} & \begin{bmatrix} s^2 \begin{bmatrix} I_H + I_I + m_{-H} l_H^2 \\ +m_{-H} \rho_4^2 + m_{122} \rho_5^2 \\ +2m_{122} d_2 \\ +2m_I l_H \rho_4 \sin(\beta - \vartheta) \\ +M_\theta s + m_I g \rho_4 \sin \beta \\ +m_{122} g d_1 \\ +m_I g l_H \cos \vartheta \end{bmatrix} \\ \begin{bmatrix} -m_{122} L d_1 s^2 \\ -m_I l_H \cos \vartheta s^2 \\ -m_I \rho_4 \sin \beta s^2 \end{bmatrix} \end{bmatrix} & \begin{bmatrix} -m_{122} L d_1 s^2 \\ -m_I l_H \cos \vartheta s^2 \\ -m_I \rho_4 \sin \beta s^2 \end{bmatrix} & \begin{bmatrix} -\pi_1 d_1 s^2 \end{bmatrix} \\
 \begin{bmatrix} -L X_{uI} \\ -m_{-H} L s \end{bmatrix} & (-L X_{wI}) & \begin{bmatrix} -m_I L l_H \cos \vartheta s^2 \\ -m_I L \rho_4 \sin \beta s^2 \\ -m_{122} L d_1 s^2 \end{bmatrix} & \begin{bmatrix} m_{-H} L^2 s^2 \\ +L g m_{-H} \end{bmatrix} & \begin{bmatrix} \pi_1 L s^2 \end{bmatrix} \\
 (-\pi_1 s) & - & \begin{bmatrix} -\pi_1 d_1 s^2 \end{bmatrix} & \begin{bmatrix} \pi_1 L s^2 \end{bmatrix} & \begin{bmatrix} I_{12} s^2 \\ +2\pi_2 s^2 \\ +\pi_1 g \end{bmatrix}
 \end{bmatrix}
 \begin{bmatrix} u(s) \\ w(s) \\ \theta(s) \\ \lambda(s) \\ \psi(s) \end{bmatrix} =$$

Preceding page blank



$$\begin{bmatrix}
 \left( s^2(-m_{-H}L) \right) & \left( s^2(-\pi_1) \right) \\
 - & - \\
 \left\{ \begin{array}{l} -m_{122}Ld_1s^2 \\ -m_I L \ell_H \cos \vartheta s^2 \\ -m_I L \rho_4 \sin \beta s^2 \end{array} \right\} \left( -\pi_1 d_1 s^2 \right) \\
 \left[ \begin{array}{l} m_{-H}L^2s^2 \\ +Lgm_{-H} \end{array} \right] & \left[ \pi_1 L s^2 \right] \\
 \left[ \pi_1 L s^2 \right] & \left[ \begin{array}{l} I_{12}s^2 \\ +2\pi_2s^2 \\ +\pi_1g \end{array} \right]
 \end{bmatrix}
 \begin{bmatrix}
 u(s) \\
 w(s) \\
 \theta(s) \\
 \lambda(s) \\
 \psi(s)
 \end{bmatrix}
 =
 \begin{bmatrix}
 (X_{\delta_{col}})(X_{\delta_{cyc}}) & (-X_u - X_{uI}) & (-X_w - X_{wI}) \\
 (Z_{\delta_{col}})(Z_{\delta_{cyc}}) & (-Z_u - Z_{uI}) & (-Z_w - Z_{wI}) \\
 (M_{\delta_{col}})(M_{\delta_{cyc}}) & \begin{bmatrix} -M_u - M_{uI} \\ -\ell_H \cos \vartheta X_{uI} \\ -\rho_4 \sin \beta X_{uI} \end{bmatrix} & \begin{bmatrix} -M_w - M_{wI} \\ -M_{wI} - M_{wI}^* \\ -X_{wI} \ell_H \cos \vartheta \\ -X_{wI} \rho_4 \sin \beta \end{bmatrix} \\
 - & - & (LX_{uI}) & (LX_{wI}) \\
 - & - & - & -
 \end{bmatrix}
 \begin{bmatrix}
 \delta_{col}(s) \\
 \delta_{cyc}(s) \\
 U_g(s) \\
 \\
 W_g(s)
 \end{bmatrix}$$

One sigma wind gust is given by

$$\sigma u_g = \sqrt{2 \int_0^{\infty} p(\omega) d\omega}$$

where  $p(\omega)$  = power spectral density or power spectrum as a function of frequency  $\omega$ .

A  $1\sigma$  value wind gust corresponding to

$$V = 30 \text{ fps (average wind speed)}$$

is estimated to be 7 feet per second.

The  $1\sigma$  response of the arm is given by

$$\sigma \psi = \sqrt{2 \int_0^{\infty} K^2 M^2 p(\omega) d\omega}$$

where  $KM = \frac{\psi(s)}{u_g(s)}$  as a function of frequency

$K$ ,  $M$ , and  $p$  are Etkin's<sup>2</sup> notation, page 278.

---

2. Etkin, Bernard, DYNAMICS OF FLIGHT, New York, John Wiley & Sons, Inc., 1959.

Preceding page blank

Data used was basically the CH-47B, as tabulated below.

$$m_{12} = .311 \text{ slug}$$

$$m_2 = .467 \text{ slug}$$

$$m_H = 1025 \text{ slugs}$$

$$m_I = 31.1 \text{ slugs}$$

$$m_{122} = .778 \text{ slug}$$

$$m_{-H} = 31.9 \text{ slugs}$$

$$m = 1057 \text{ slugs}$$

$$I_{12} = 2.58 \text{ slug-ft}^2$$

$$I_I = 3110 \text{ slug-ft}^2$$

$$I_H = 200,000 \text{ slug-ft}^2$$

$$L = 20 \text{ ft}$$

$$\psi = 63^\circ 26'$$

$$\ell_H = 11.2 \text{ ft}$$

$$\beta = 0^\circ$$

$$\psi_1 = 0^\circ$$

$$\rho_4 = 10 \text{ ft}$$

$$\rho_5 = 10 \text{ ft}$$

$$\rho_9 = 5 \text{ ft}$$

$$\rho_6 = 10 \text{ ft}$$

$$X_u = 20.1 \text{ lb per (ft/sec}^{-1}\text{)}$$

$$X_w = -29.3 \text{ lb per (ft/sec}^{-1}\text{)}$$

$$Z_u = -30.5 \text{ lb per (ft/sec}^{-1}\text{)}$$

$$M_w^\bullet = 0$$

$$Z_w = 276 \text{ lb per (ft/sec}^{-1}\text{)}$$

$$\begin{aligned}
M_u &= -1300 \text{ ft/lb per (ft/sec}^{-1}\text{)} \\
M_w &= -140 \text{ ft/lb per (ft/sec}^{-1}\text{)} \\
M_\theta &= 167,400 \text{ ft/lb per (rad/sec}^{-1}\text{)} \\
X_{uI} &= .020 \text{ lb per (ft/sec}^{-1}\text{)}
\end{aligned}$$

Based on the open-loop system response analysis, the load-control crewman's response is then incorporated in the loop. To simplify the computation and assuming that helicopter pitch and vertical motions are decoupled from the dynamic system,  $w$  and  $\theta$  are dropped from the dynamic matrix.

We use 
$$\delta_{cyc}(s) = K_p e^{-\tau s} \psi(s)$$

with 
$$\tau = .3 \text{ (an effective value)}$$

Further, substituting a Pade approximation,

$$e^{-\tau s} = \frac{1 - \tau_1 s}{1 + \tau_1 s}$$

Using presented data we obtain,

$$\frac{\psi}{u_g} = \frac{\begin{bmatrix} .048 \omega^4 + .0385 \omega^2 \end{bmatrix}}{\begin{bmatrix} -11.1 \omega^6 + 59.4 \omega^4 \\ -\omega^2 (72.8 + .00192 K_p X_{\delta_{cyc}}) \\ + 8.3 \end{bmatrix}} + j \frac{\begin{bmatrix} -.319 \omega^3 - .258 \omega \end{bmatrix}}{\begin{bmatrix} 74.2 \omega^5 - 388 \omega^3 \\ + \omega (438 - .0128 K_p X_{\delta_{cyc}}) \end{bmatrix}}$$

Using the same method described in the previous section,

$$\sigma \psi = .025 \text{ radian or } 1.43 \text{ degrees}$$

For a 12-foot acquisition hook arm, this represents a  $1\sigma$  motion of 0.3 foot between the hook and the lifting provision of the load.

# LIST OF SYMBOLS

B	center of gravity of intermediary body
G	center of gravity of helicopter
$H_1$	forward cable suspension point
$H_2$	aft cable suspension point
$\bar{i}$	unit vector along x
$I_H$	inertia of helicopter about y axis thru G
$I_I$	inertia of intermediary body about y axis thru B
$I_{12}$	inertia of hook $P_1P_2$ about y axis thru c.g. $P_3$ (except for mass at point $P_2$ )
$\bar{k}$	unit vector along z
$L'$	"Lagrangian Function" or $(T - V)$
L	length of cable or distance from point $H_1$ to point $R_1$ or distance from point $H_2$ to point $R_2$
$\ell_H$	distance from point G to $H_1$ or from G to $H_2$
m	$m_H + m_I + m_{12} + m_2$
$m_H$	mass of helicopter
$m_{-H}$	$m - m_H$
$m_I$	mass of intermediary body
$m_2$	mass at point $P_2$
$m_{12}$	mass of hook $P_1P_2$ about y axis thru c.g. $P_3$ (except for mass at point $P_2$ )
$m_{122}$	$m_{12} + m_2$

# LIST OF SYMBOLS - Continued

$M$	pitching moment, positive for various moments
$M_u$	$\frac{dM}{du}$
$M_{uI}$	$\frac{dM}{du}$ of intermediary body
$M_w$	$\frac{dM}{dw}$
$M_w^\bullet$	$\frac{dM}{d\dot{w}}$
$M_{wI}$	$\frac{dM}{dw}$ of intermediary body
$M_{wI}^\bullet$	$\frac{dM}{d\dot{w}}$ of intermediary body
$M_{\dot{0}}$	$\frac{dM}{d\dot{\theta}}$
$M_{\delta_{col}}$	$\frac{dM}{d\delta_{col}}$
$M_{\delta_{cyc}}$	$\frac{dM}{d\delta_{cyc}}$
$P_1$	top of free-floating hook
$P_2$	bottom of free-floating hook
$P_3$	center of gravity of free-floating hook (not counting mass at point $P_2$ )
$q_i$	generalized coordinate or one of the degrees of freedom of the system
$\dot{q}_i$	$\frac{dq_i}{dt}$ or rate of change of $q_i$ with time

# LIST OF SYMBOLS - Continued

$Q_i$	generalized force or the coefficient of $\delta q_i$ when summing up virtual work
$R_1$	attachment point of forward cable to intermediary body
$R_2$	attachment point of aft cable to intermediary body
$T$	kinetic energy of entire system
$u$	$\dot{x}_H = \frac{dx_H}{dt}$ velocity of helicopter along its x body axis, positive "forward" (perturbation velocity or actual velocity in this case, since we are dealing with hover)
$u_g$	gust velocity along x body axis, positive "forward"
$V$	potential energy of entire system
$w$	$\dot{z}_H = \frac{dz_H}{dt}$ = velocity of helicopter along its z body axis, positive "downward" (perturbation velocity or actual velocity in this case, since we are dealing with hover)
$w_g$	gust velocity along z body axis, positive "down"
$x$	horizontal, positive when (substantially) in same direction as forward motion of helicopter
$x_H$	motion of helicopter c.g. along its x body axis, positive "forward"
$X$	force along x body axis, positive "forward"
$x_u$	$\frac{dX}{du}$
$x_{uI}$	$\frac{dX}{du}$ of intermediary body
$x_w$	$\frac{dX}{dw}$

# LIST OF SYMBOLS - Continued

$x_{wI}$	$\frac{dx}{dw}$ of intermediary body
$x_{\delta col}$	$\frac{dx}{d\delta_{col}}$
$x_{\delta cyc}$	$\frac{dx}{d\delta_{cyc}}$
$z$	vertical, positive "down"
$z_H$	motion of helicopter c.g. along its $z$ body axis, positive "down"
$Z$	force along $z$ body axis, positive "down"
$z_u$	$\frac{dz}{du}$
$z_{uI}$	$\frac{dz}{du}$ of intermediary body
$z_w$	$\frac{dz}{dw}$
$z_{wI}$	$\frac{dz}{dw}$ of intermediary body
$z_{\delta col}$	$\frac{dz}{d\delta_{col}}$
$z_{\delta cyc}$	$\frac{dz}{d\delta_{cyc}}$
$\beta$	angle between the horizontal and either line $R_1B$ or line $R_2B$ (when $\theta = 0$ )
$\vartheta$	angle between the vertical and line $GH_1$ or angle between vertical and line $GH_2$ (when $\theta = 0$ )
$\vartheta_1$	angle between the horizontal and line $BP_1$ (when $\theta=0$ )
$\theta$	pitch (attitude) positive when nose of helicopter is up



### LIST OF SYMBOLS - Concluded

$\dot{\theta}$	$\frac{d\theta}{dt}$ or rate of change of $\theta$ with time
$\lambda$	angle between vertical and either cable (positive when bottom of cable is aft of top of cable)
$\dot{\lambda}$	$\frac{d\lambda}{dt}$ or rate of change of $\lambda$ with time
$\delta_{col}$	collective stick motion
$\delta_{cyc}$	cyclic stick motion
$\rho_4$	distance from point $R_1$ to point B or from point $R_2$ to point B
$\rho_5$	distance from point B to point $P_1$
$\rho_6$	distance from point $P_1$ to point $P_2$
$\rho_9$	distance from point $P_1$ to point $P_3$
$\rho_{96}$	a distance used to represent either $\rho_9$ or $\rho_6$ so as to avoid duplicate derivations
$\psi$	angle between the vertical and line $P_1P_2$ , positive when $P_2$ is aft of $P_1$
$\dot{\psi}$	$\frac{d\psi}{dt}$ or rate of change of $\psi$ with time
$\delta$	an operator signifying a possible small change in the variable following it
$\delta_x$	a "virtual" displacement in x
.	dot over a variable indicates the time derivative